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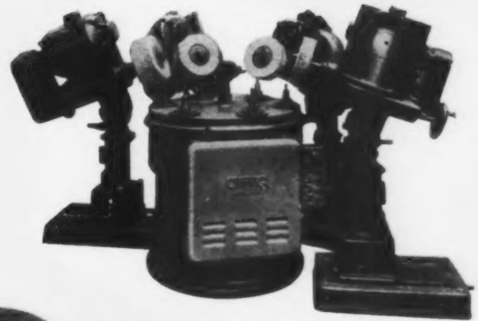

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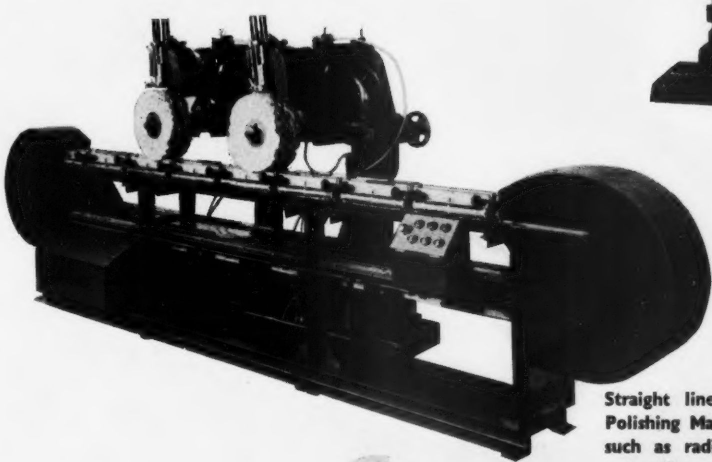

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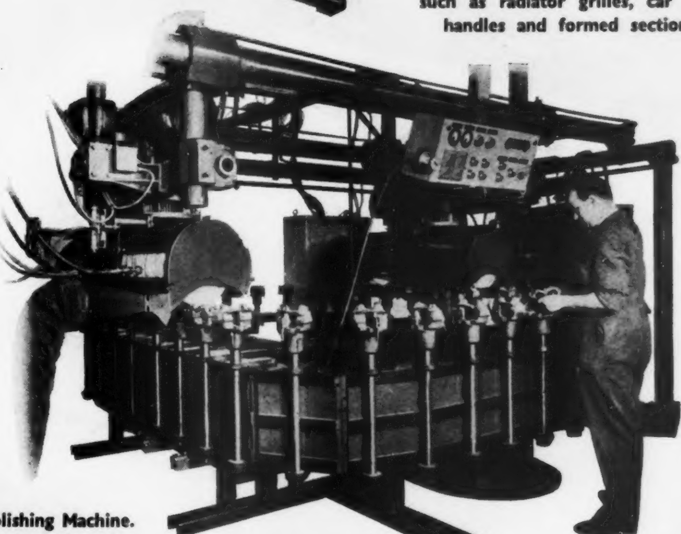

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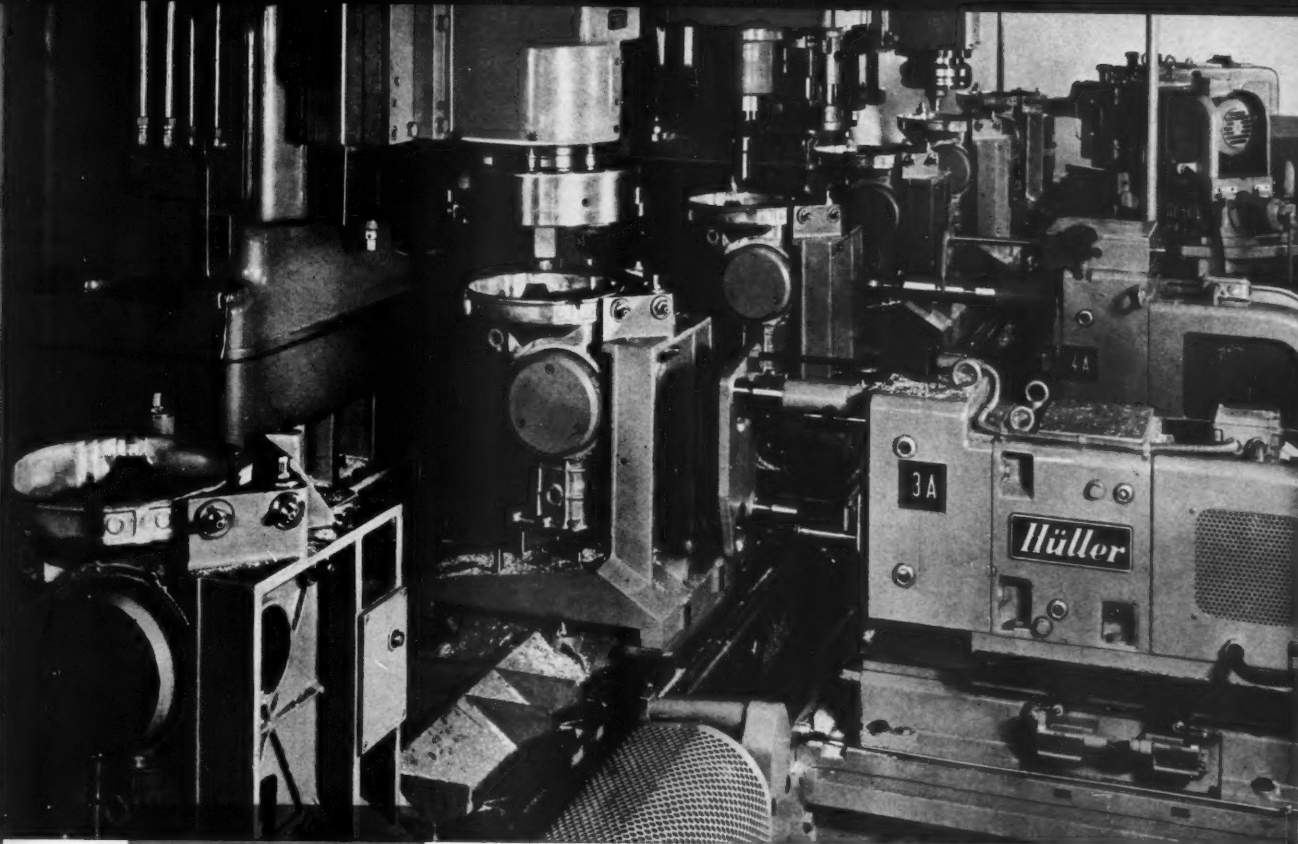
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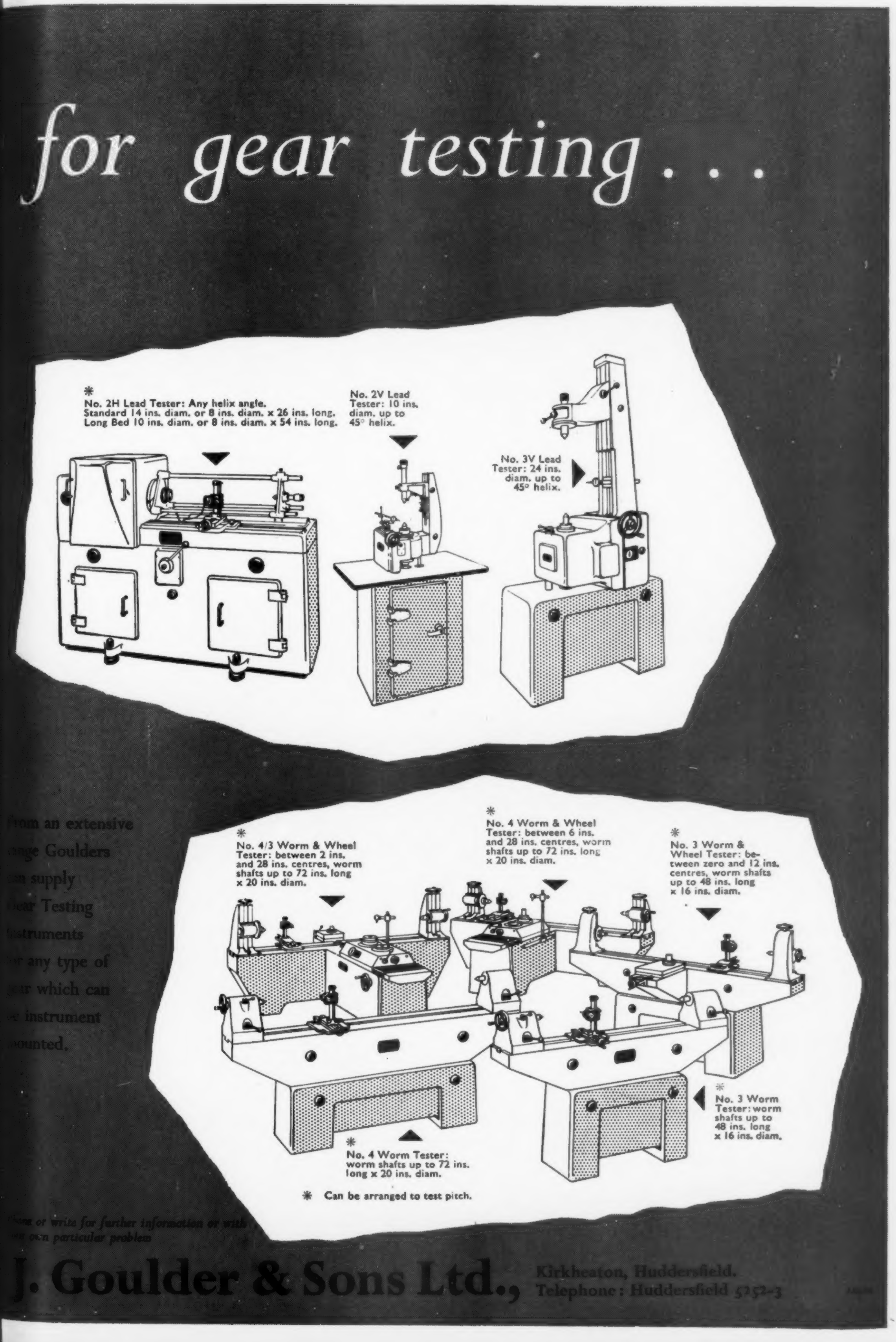
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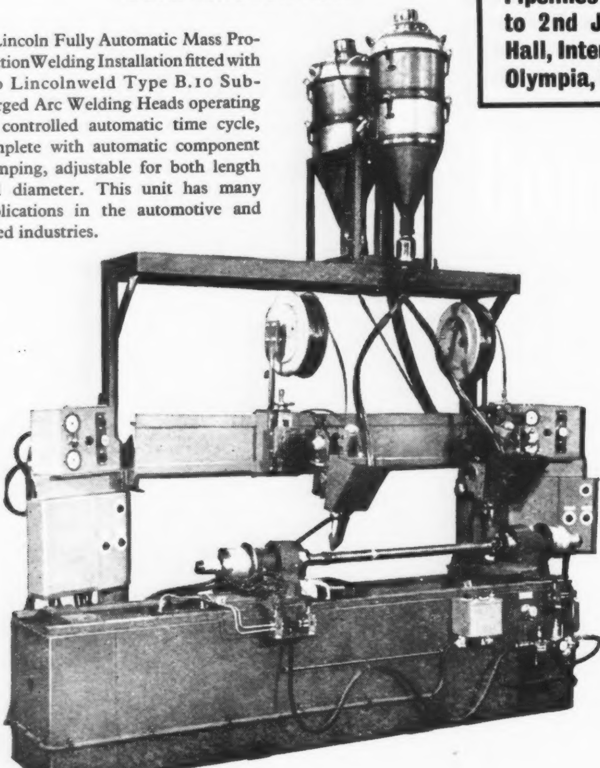

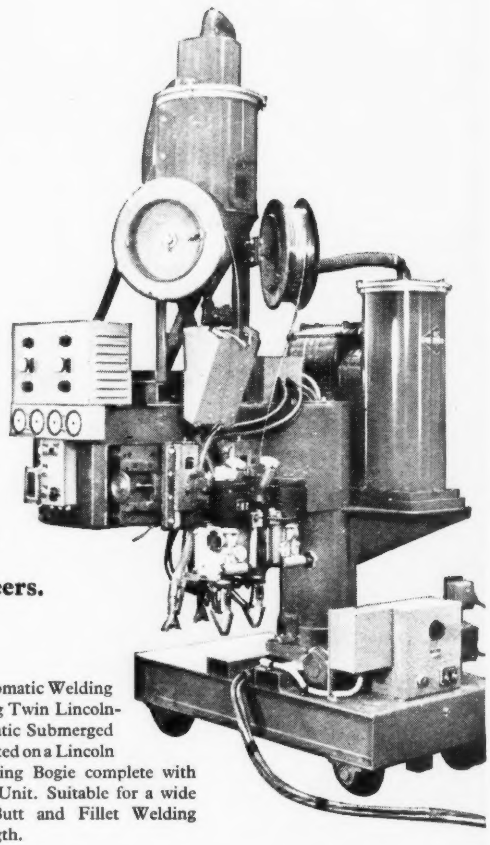

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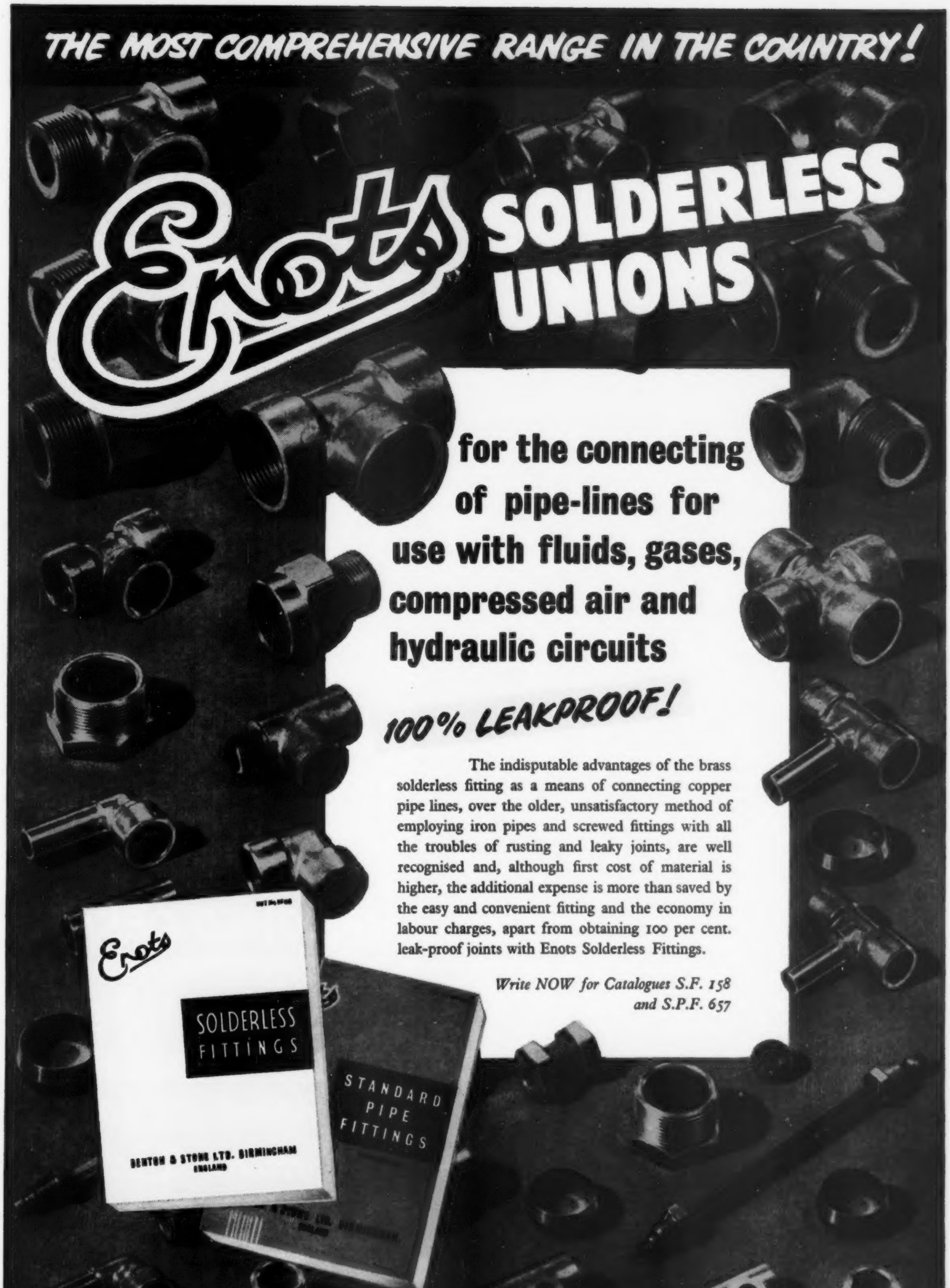
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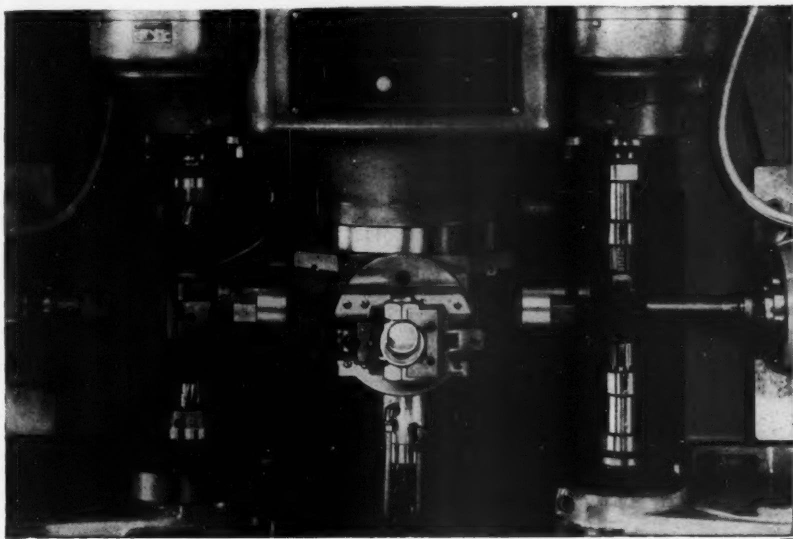

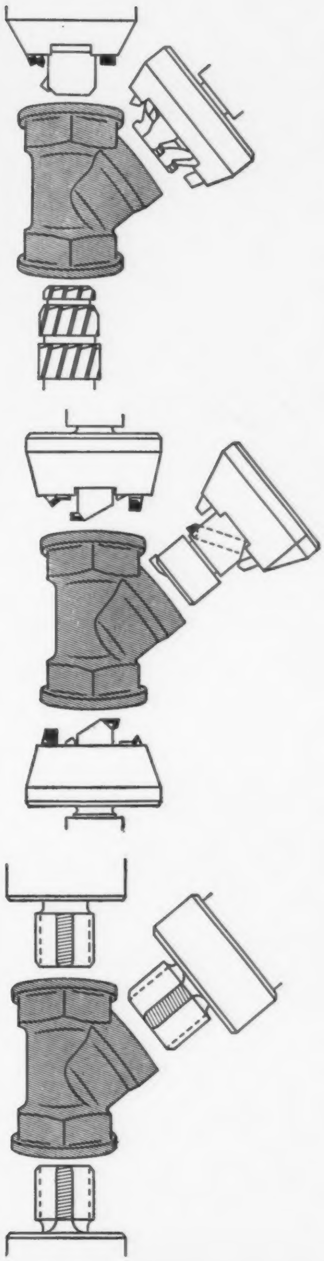

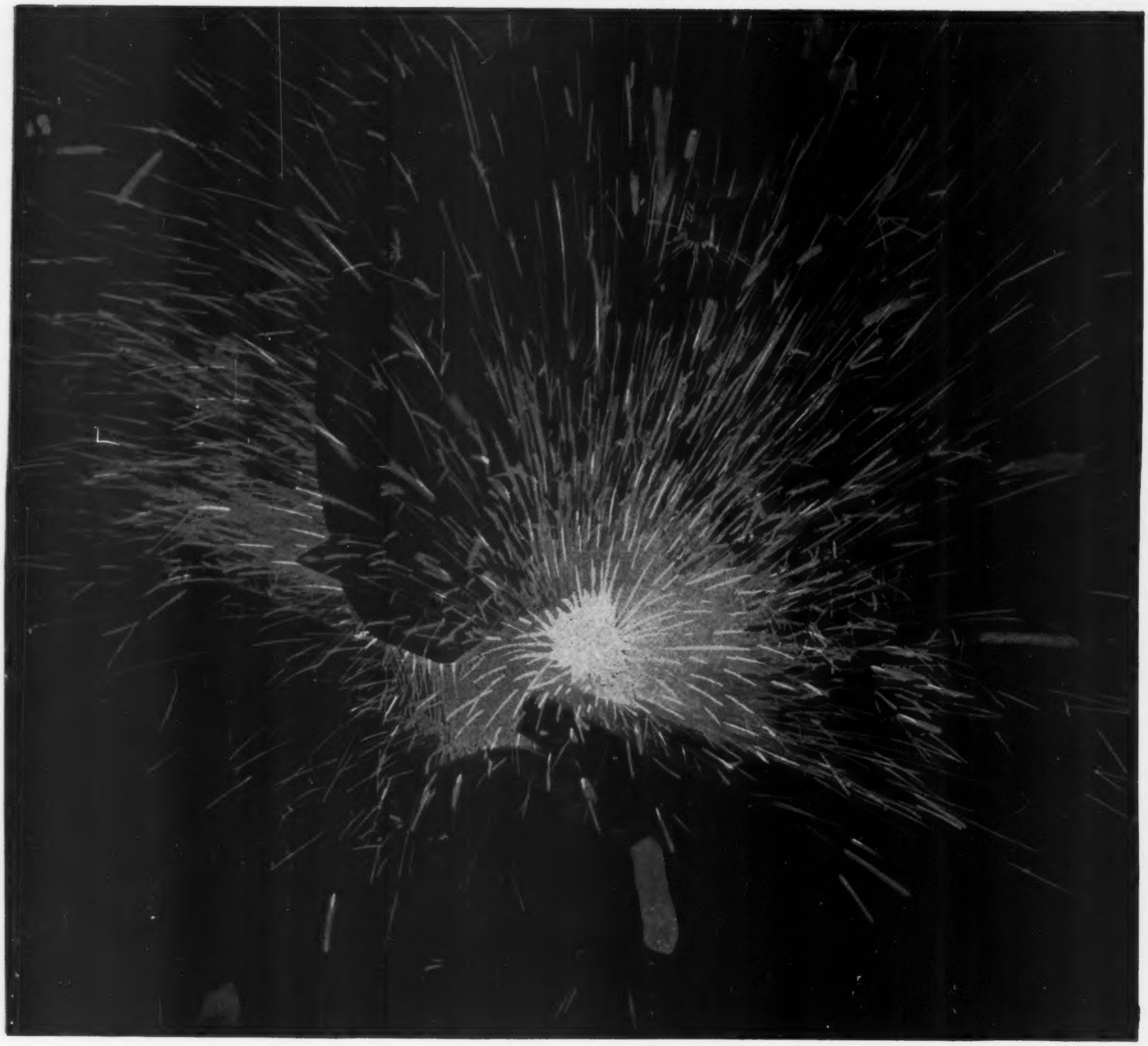

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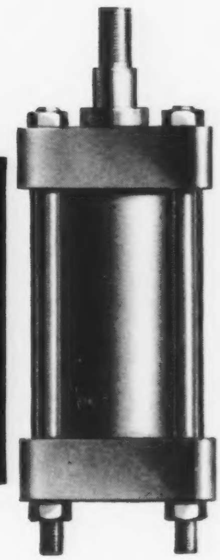

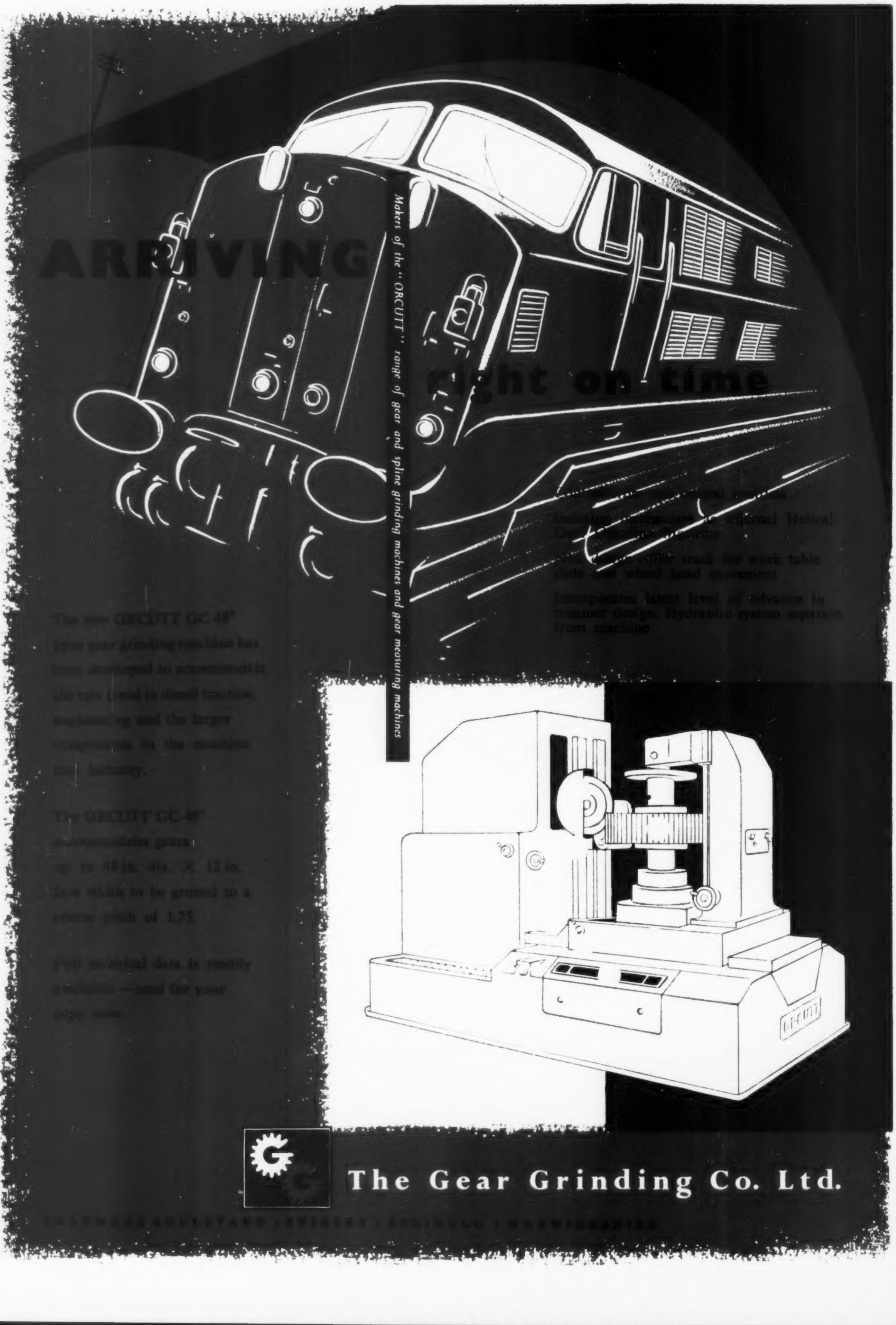
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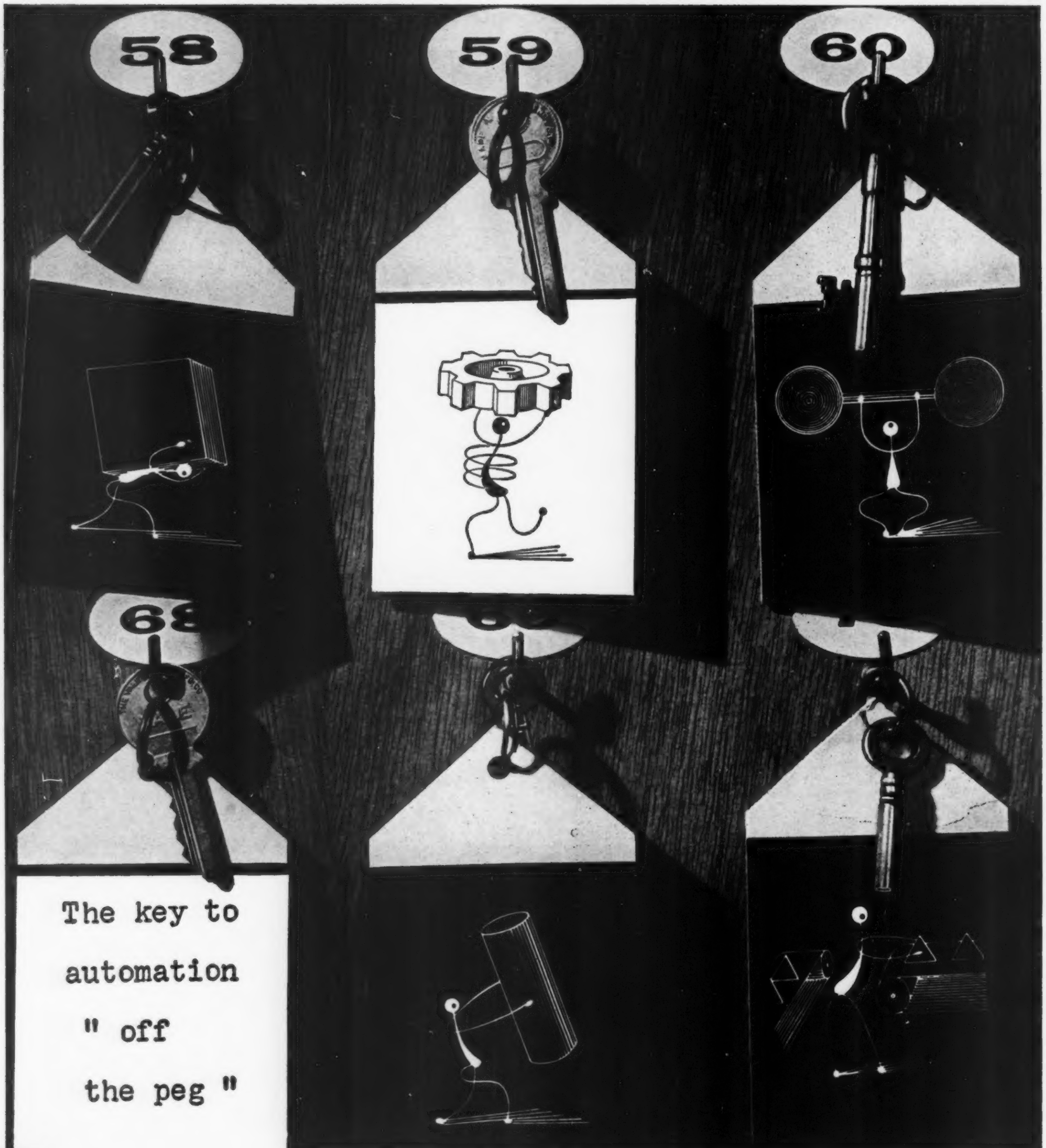
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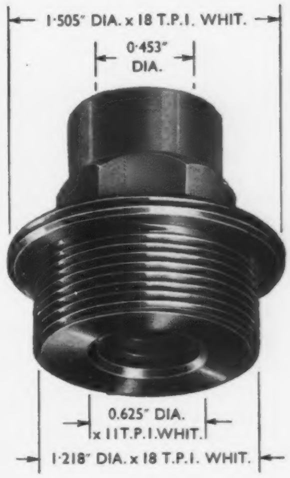

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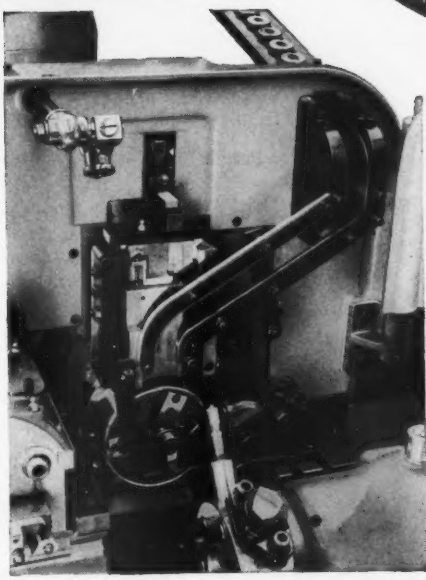

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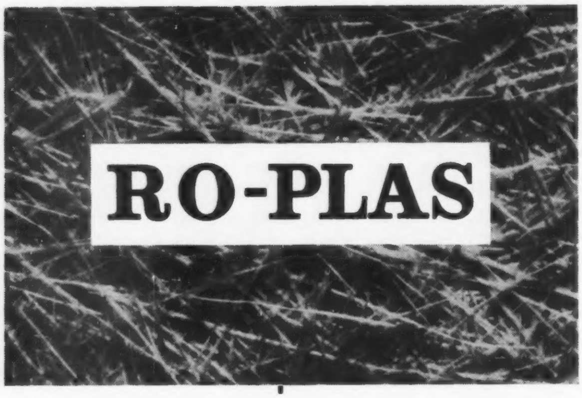

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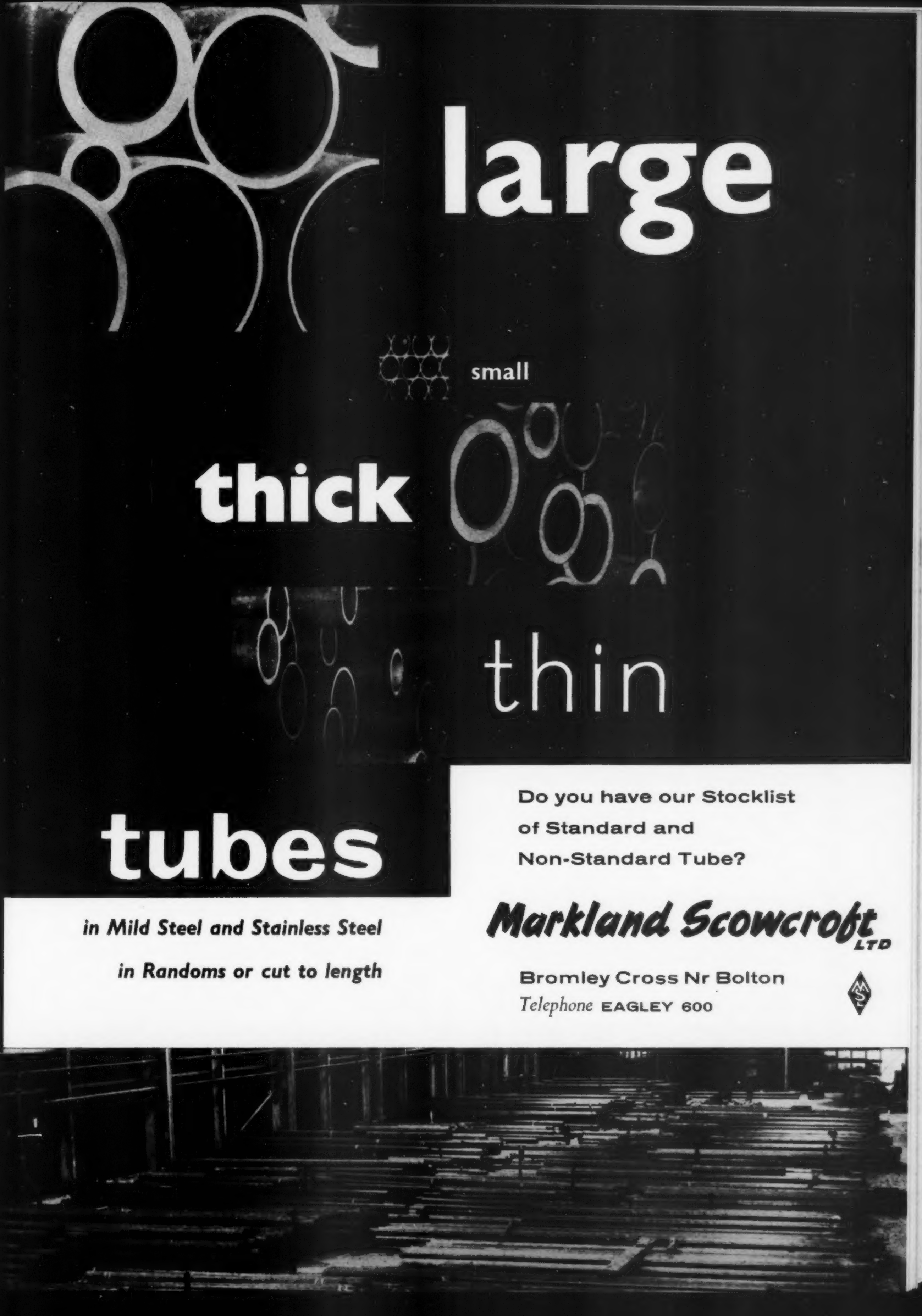
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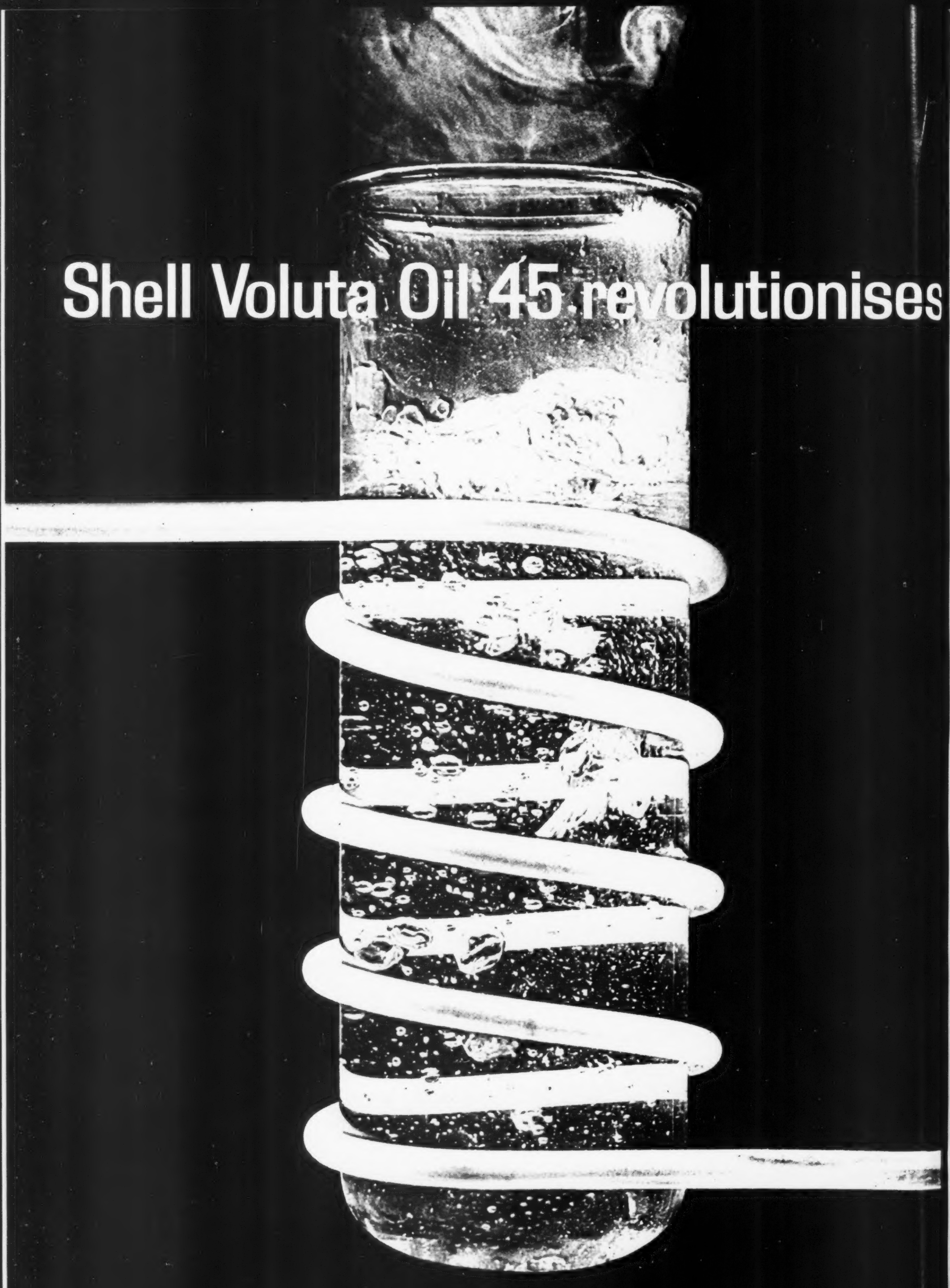
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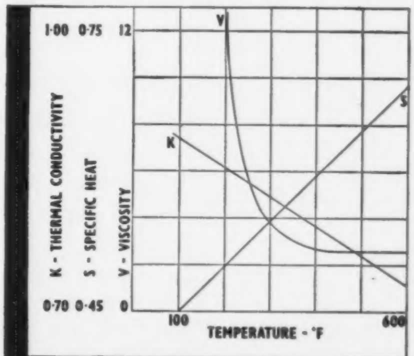

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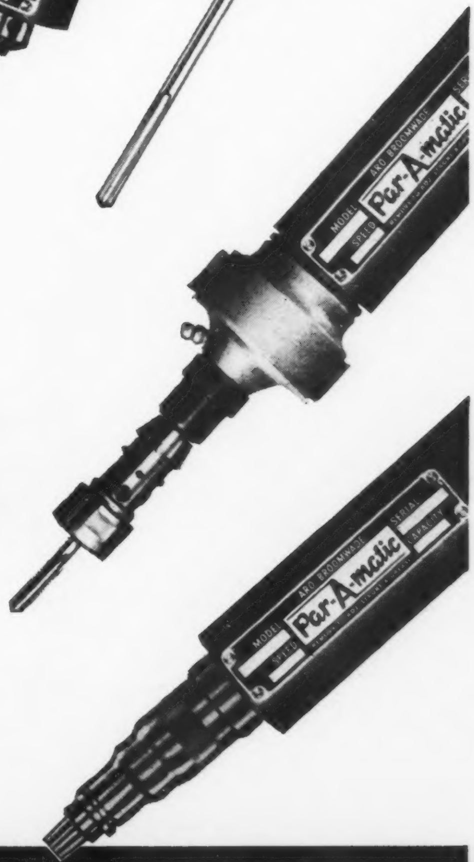

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The Production Engineer

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VOL. 39 No. 5 MAY, 1960

PRECISION GRINDING RESEARCH

by H. GRISBROOK, B.Sc.(Birm.), A.M.C.T., M.I.Prod.E.

Department of Engineering Production,

University of Birmingham.

This Paper — condensed from a research thesis — is a first report on a current research project in the postgraduate Department of Engineering Production in the University of Birmingham.*

The work is being carried out on a Churchill 8 in. × 16 in. Plain Surface Grinding Machine, equipped with a specially designed dynamometer capable of operating at a maximum table traverse speed of 38 ft. per minute under wet grinding conditions.

To indicate the need for this investigation and the significance of the preliminary findings, this Paper begins with a survey of previous work.

* H. Grisbrook: "Precision Grinding" Official Degree Thesis. Department of Engineering Production, University of Birmingham, May, 1959.

A MAJOR step forward in the field of research in precision grinding was made at M.I.T. in 1952 by Shaw and his associates, who developed a dynamometer [1] by means of which the direct tangential and normal forces in surface grinding were first measured.

In 1915, J. J. Guest [2, 3] had developed certain theories based purely on the geometrical relationships between the grinding wheel and work, their dimensions and speeds, and the depth of cut, and the M.I.T. experiments found some measure of agreement with these theories.

However, the M.I.T. dynamometer was restricted to dry grinding and thus to a maximum work speed of 16 f.p.m., the majority of the runs being carried out at 4 f.p.m.

These particularly low work table speeds, as noted by Tarasov in the discussion on Shaw's Paper, imposed limitations which cramped further development. Nevertheless, the establishment of the co-efficient of grinding, and the specific energy in grinding, provided a basis for further investigation.

The significance of chip thickness as the important variable in relation to specific energy and surface temperature has received considerable attention from earlier workers [4, 5, 6, 15, 18], the main interest being to explain the very high specific energy in grinding as compared with milling and single point metal cutting.

The application of Merchant's theory of the mechanics of the metal cutting process, and the hypothesis that grinding is analogous to milling [4, 5], has led to the determination of the rake angle of the chips from the assumption that the radial and tangential forces are the main fundamental parameters as in milling.

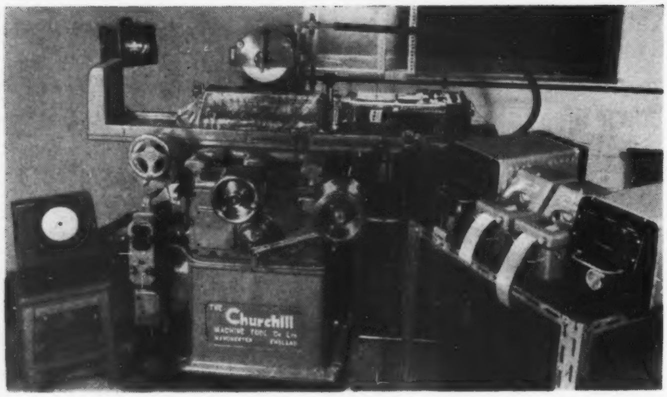


Fig. 1.
General view of the equipment.

This preoccupation has ignored Boston's suggestion ([4] discussion) that chip removal by a negative rake grit, with its attendant end friction, may follow a different law from that associated with sharp edge cutting tools. In this direction, however, Hahn in 1956 [9] introduced his "rubbing end grain hypothesis" and emphasised the fundamental importance of the dull grit.

The zero clearance, resulting from diamond truing to spark out, serves to emphasise the rubbing grain theory and Hahn extends this by accepting rubbing as the main source of heat in grinding. The fact that the ratio $\frac{\text{Tangential Force}}{\text{Normal Force}} = 2$ for turning and only $\frac{1}{2}$ for grinding, suggests a fundamental difference which is supported by the large difference between specific energies for the two operations [9].

In his defence of the role of chip thickness in grinding, Reichenbach [15] suggests that chip thickness will maintain its significance in relation to specific energy independent of prevailing conditions.

On the contrary, Hahn claims [9] that below a particular chip thickness (less than .0004 in.), there are conditions when only dust and not grinding chips are produced.

Thus it seems possible that there are two different mechanisms of metal removal in grinding, and that at some stage the process changes from one predominantly of cutting as comparable with the milling operation, to one of rubbing. Such a suggestion does not depend on the theory of critical chip thickness [4] where theoretical shear strength of the work material is involved.

Further support is given to this theory of the rubbing grain by the role of sliding friction in Region III, on the graph, in the Paper by Mayer and Shaw [21].

It will be seen, later, that this present research confirms this hypothesis.

grit size

The influence on chip width of the size of the individual grit has been determined from a taper section of a ground surface [4].

Guest proved that grit spacing is inversely proportional to the square of the average linear dimension of the grit, therefore the forces *should* vary in some relation to grit size. This proved to be the case in [1], where higher specific energy resulted for grit sizes coarser or finer than the optimum for the conditions considered. This was also observed by Landberg [7].

Mr. Grisbrook is Lecturer in Tool Engineering and Metrology in the Department of Engineering Production, University of Birmingham. After serving his apprenticeship with Messrs. Pollock and MacNab, Mr. Grisbrook was employed for 12 years by The Churchill Machine Tool Company Limited and subsequently held lecturing appointments at the Stockport, Wolverhampton and Wednesbury Technical Colleges. As an Associate of the Manchester College of Technology and a Member of The Institution of Production Engineers, Mr. Grisbrook joined the staff of the University of Birmingham in 1950, and has recently been awarded an official research degree for his work on Precision Grinding.

wheel selection

In industrial practice, this is a problem of adjustment of bond hardness to grinding conditions [18, 22] and Tarasov (discussion [1]) expounds the principle of wheel wear as a result of bond-post failure.

Merchant [5] did not experience bond-post rupture during the experiment involving wheel grades of H, I, J, K and L. Wheel wear was attributed to fracture of the grit. Merchant did, however, " mention as a point of interest, that bond-post rupture was later experienced at a chip area a small amount greater than the maximum used in the experiment ". The maximum chip thickness was of the order of 25μ, which is not a condition of normal stock removal.

Landberg [7] found that there was an optimum wheel hardness, and that vibrations developed much earlier in wheels softer or harder than the optimum grade.

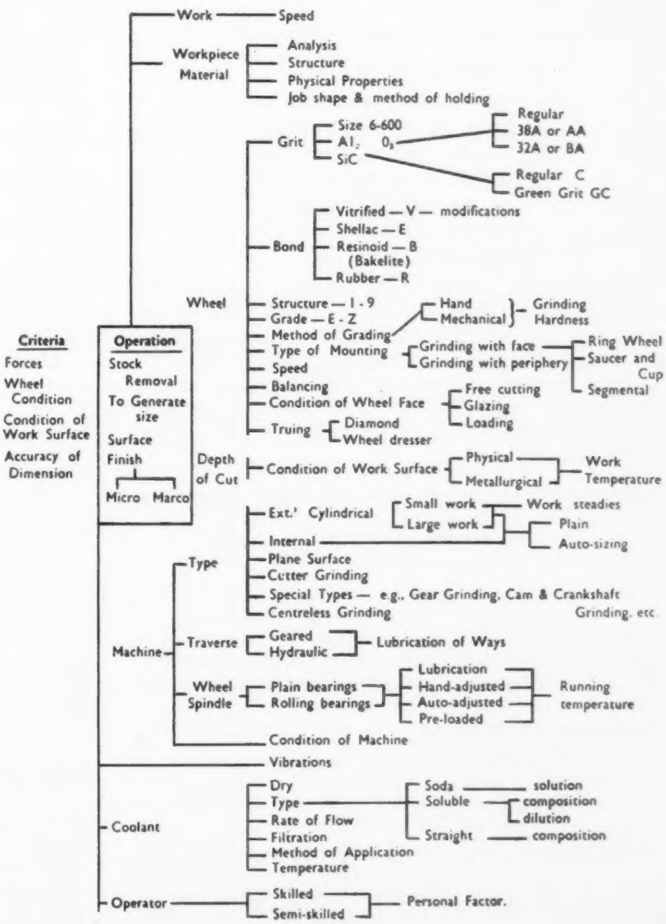
In view of the emphasis on the importance of the hardness of wheels, accepted in industry, there is need for more consideration to be given to this factor during investigations. It is summed up by Hahn [9] in the final paragraph — " . . . any grinding theory, if it is to be realistic . . . should contemplate the very real differences between sharp and dull grits and between soft and hard wheels ".

The theories concerning the mechanism of grinding, expounded by the above workers, serve to emphasise the complexity of the process. (see " Variables in Grinding ", Table I). It is involved with wheel speed, work speed, rate of feed, arc of contact between wheel and work, type and size of grit, type and hardness of bond, variations in work material and its hardness, wet or dry grinding and the machine conditions. It is further complicated by the multitudinous orientation of the grits over the working surface of the wheel and by the random values of cutting angles and clearance angles of the individual grits.

In addition the idiosyncrasies of wear and fracture of the grits, a constant recurring process, are individual characteristics not yet understood.

TABLE I

LIST OF VARIABLES IN PRECISION GRINDING



These variables are superimposed on three possibly different requirements of :-

(i) stock removal;
(ii) production of size;
(iii) production of fine surface finish.

Thus, it will be appreciated that it can be possible for theories to be developed, which are apparently contradictory, but unless all the relative factors are comparable, the findings cannot be compared.

In view of the wide range of variables, it is to be expected that investigations will be based upon some industrial practice, where experience has taught control of a majority of the variables involved, and thus permit concentration on a limited range.

Furthermore it will be inevitable that findings in the early stages will be related to, and compared with, existing grinding practice.

The following selected findings of past research are involved in this report :-

chip thickness

A widely accepted formula has been evolved [4]

$$t = \sqrt{\frac{4\, V_M}{V_W C\, r} \sqrt{\frac{d}{D}}}$$

where t = chip thickness
V_M = work speed in f.p.m.
V_W = wheel speed in f.p.m.
C = number of effective grits per sq. in. of grinding wheel face.
r = ratio of width to depth of scratch generated by a grit.
d = depth of cut.
D = wheel diameter.

With decrease in chip thickness, shear stress, on the shear plane [5], increases until a critical chip thickness in the region of 30×10^{-6} in. is reached. Below this value, grinding forces and specific energy for all hardnesses of steel are constant [4]. Fine grit wheels have higher values of C, and therefore produce thinner chips, which results in higher specific energy (Reichenbach) [9].

ratio of forces in up-grinding and down-grinding

$$\frac{F_{T_U}}{F_{T_D}}$$

Letner and Backer, Marshall and Shaw found this ratio to be unity at 4 f.p.m., while Tarasov [1] found a 20% increase for table traverse speeds of 60 f.p.m.

co-efficient of grinding

F_T = normal forces.

F_N = tangential forces

This ratio F_T/F_N has been found [1] to be in the region of 0.5, as compared with a value of 2 for single-point cutting. Because of its similarity with the ratio for the co-efficient of friction, it is given this name of co-efficient of grinding. Higher forces and lower co-efficients of grinding were experienced with silicon-carbide grit wheels, as compared with wheels of aluminium oxide grit.

specific energy

The energy, measured in in.-lb. per cubic inch of metal removal, was found to be approximately 10×10^6 in.-lb. per cubic inch for "A" wheels and 25×10^6 for "C" wheels [1]. This is compared with 0.5×10^6 in.-lb. per cubic inch for single point cutting [1, 5]. Specific energy increased as depth of cut decreased. This was observed at 4 f.p.m. work speed. Tarasov (discussion [1]), claimed that specific grinding energy increased roughly ten-fold as table speed was decreased from 60 f.p.m. to 5 f.p.m. and that most of the rise occurred below 20 f.p.m.

material hardness

In references [1, 4, 5] there was no significant difference in the specific energy for different hardnesses of steel. This was reasoned to result from the increase in shear strength being compensated by the reduction of friction for the harder steels. This also was for slow table speeds and again Tarasov claims that for higher table speeds, compatible with industrial practice, there is considerable variation of horizontal forces and of specific energy, with changes in Rockwell hardness for a given steel.

grit spacing

Hahn [10], basing his reasoning on the elastic characteristic of the wheel bond, anticipated an increase in the number of grits in action under heavier loads. Tests of rolling grinding wheels, under various loads over smoked screens, proved that although the grit images increase in size with load, there was no appreciable increase in their number [15].

wheel wear

Metal removal was claimed as the only variable affecting wheel wear [6]. It was found, however [8], that by excessive feed, wheel wear increased and could exceed metal removal.

wheel dressing

The shape of the truing diamond, its speed of cross-traverse, and the technique of dressing are recognised as important factors in the grinding forces and the degree of repetition of results [1, 9, 10, 11]. With diamond truing, the individual grits are cut and clearance angles reduced to zero [2, 9].

Wheel crushing results in cooler cutting and lower grinding forces than diamond dressing. Unequal hardness around the circumference of the wheel was experienced and unwanted taper on the wheel results [20].

rake angle

Working from comparisons of tool friction with positive and negative rake angles when turning, Backer and Merchant concluded that the chip rake angle was –30°. Backer, Marshall and Shaw [4] assumed zero rake on the probability of having as many grits with positive as with negative rakes.

thermal conditions

Heat generated by grinding determines both work surface conditions and the forces involved. Lower temperatures occur at higher work speeds, Hahn [9].

The heat wave, which moves with grinding along the workpiece, caused higher forces over a longer workpiece [1].

Chao and Trigger (in discussion of Ref. [1]) "... the temperature gradient ahead of the grinding zone is extremely steep, and, with a downfeed of 0.001 in. it should make little difference whether the length of the specimen is $\frac{1}{2}$ in. or 3 in. insofar as its effect on volumetric expansion is concerned." Temperatures at the chip-grit interface exceed the melting point of steel, but, as melting is a time-temperature reaction, melting does not occur [6]. Practically all of the 10^7 in.-lb. per cubic inch involved in grinding will appear in the form of thermal energy [6].

Outwater and Shaw claim that 35% of shear plane energy passes, as heat, into the workpiece [6]. Grit-chip source of heat is not expected to supply heat to the workpiece (Hahn [9]). Shear plane energy is 50% of total energy [6].

Hence less than 20% of total heat passes into the workpiece if Merchant's [5] analogy with milling is correct.

residual stresses

Stress effects in the ground surface are deeper than the depth of cut and of a magnitude higher than the yield point [12, 13].

cutting fluids

Grinding oils result in lower temperatures than water-based fluids. This suggests that superior lubrication action more than offsets their poorer cooling capacity relative to water-based materials [21].

vibrations

Waviness of wheel and work periphery develops during grinding and leads to vibrations. Grinding forces fall as vibrations develop [7].

programme of research

The current research commenced with the design and development of a grinding dynamometer on similar lines to the M.I.T. instrument, but capable of working at the maximum table speed (38 f.p.m.) under wet grinding conditions. The first objective was to determine the reliability of the equipment by comparison of results with those of earlier workers, where equivalent conditions could be established. The second objective was to plan the experiments to cover as wide a field as possible within the range of the equipment. To assist in this selection an analysis of the variables in precision grinding was made (Table I).

It was anticipated that, from a survey of the results, it would then be possible to make selections of particular factors for subsequent detailed and basic analysis.

Thus, the report which follows is in the nature of a reconnaissance, but, as is always hoped for in such surveys, certain relationships have been observed from which preliminary conclusions can be made. In regard to these conclusions, it still remains necessary to repeat the operations, so as to provide a sample sufficiently large to ensure an accurate statistical analysis.

The work has been concerned with :-

(a) the magnitude and characteristics of the normal and tangential forces at the work wheel interface for selected combinations of depths of cut and work speeds;
(b) the specific energy under these varying grinding conditions;
(c) the measurement of wheel and table speeds under the grinding load;
(d) the relationship between up and down grinding conditions;
(e) the change in the pattern of the forces as grinding proceeds;
(f) the change in the character of the working surface (the grit and bond) of the wheel with changes observed at (e);
(g) the specific energy in relation to chip thickness and rate of metal removal.

The studies, so far, have been undertaken with wheels of three widely different grades, two types of grit of three different sizes, and on three different samples of work material, viz: two hardnesses of steel and one of cast iron.

equipment

The grinding machine used for these investigations is an N.B. Model Surface Grinder manufactured by The Churchill Machine Tool Company Limited, and is a standard production model having an infinitely variable hydraulic table traverse with a maximum speed of 38 f.p.m. The grinding wheel spindle main bearings are of bronze, pad lubricated, and of the standard design adopted by The Churchill Company.

vertical feed

The machine has been modified to provide automatic vertical feeds in increments of 0.00005 in.

The feeds adopted during this first investigation were :-

$$0.05,\ 0.1,\ 0.2,\ 0.3 \times 10^{-3} \text{ in.}$$

the dynamometer

A diagram of the special dynamometer — already referred to — is given in Fig. 3, and a photograph in Fig. 2.

Referring to Fig. 3 :

A vertical cantilever post carries the horizontal force and horizontal beams support the vertical force. The basic feature is that isolation of these two forces is ensured by the steel wire linkage, between the work fixture and the vertical post. The work fixture is mounted on an aluminium bridge, to which are bolted the support beams. An aluminium intermediate plate carries four inverted vee blocks, one at each corner of the plate, and the beams are supported on pins housed in the top of these blocks. The vee blocks ride on four steel balls providing kinematic location, by being supported in vee and flat location blocks fixed to the steel baseplate.

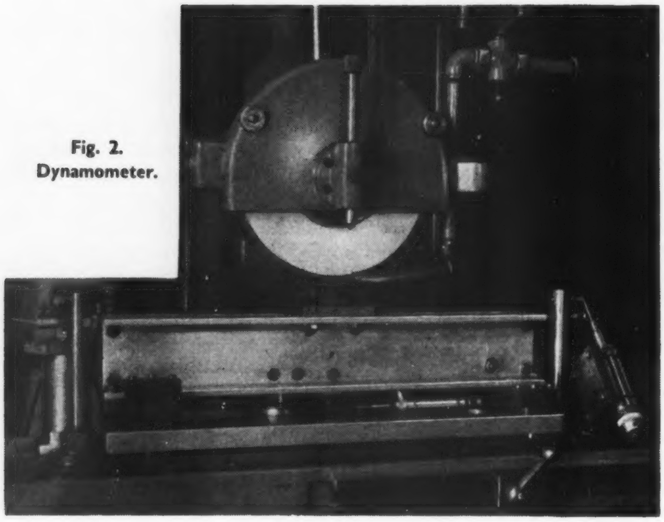


Fig. 2. Dynamometer.

horizontal deflection system demands that this second post shall be deflected, due to the initial tensioning, by an amount greater than the total deflection, to be encountered during grinding, of the primary post. Thus the secondary post is of smaller diameter and hence of different frequency than the primary post.

wheel speed

The wheel and work speed indicator are illustrated in Fig. 4. For the wheel-speed an E.M.I. Electronic Tachometer, Type 2, Serial No. 060, is used. This instrument which employs a probe receiving impulses from a disc mounted on the wheelspindle driving pulley, has been fitted with a jack and fed into an A.C. Cossor, Model 1049 Oscilloscope. A 6-volt current, from Nife batteries, is put across the input terminals of the oscilloscope so that the beam movement, on the screen, covers the speed range from 1,700 to 2,500 r.p.m.

Horizontal anchorage of the beams to the intermediate plate is by means of steel feeler strip which is fixed to the ends of the beams, immediately above the support pins, and secured by dowels and screws into the top of the vee blocks. A side acting Talymin gauge, strapped to the intermediate plate, engages the head of a screw housed in the bridge and vertical deflections, due to grinding forces, are recorded on a rectilinear tape recorder fed from the Talymin gauge.

The horizontal forces are similarly recorded from deflections of the vertical post, picked up by a Talymin gauge, which engages the head of a screw fitted in the top of the post. The horizontal beams consist of two cantilevers and a simple beam, affording three-point support for the bridge. These beams and the vertical post were designed so as to permit replacements by beams of varying rigidity, to meet the requirements of different investigations. To damp the vertical vibrations an oil dash-pot was incorporated underneath the bridge. The steel wire was tensioned by a further wire extending from the work fixture to a second vertical cantilever post at the opposite end of the bridge. Satisfactory functioning of the

stroboscope

For purposes of calibration the actual spindle speed is measured by means of a Dawes Stroboflash Type 1200D.

table position and traverse speed

Fig. 4 shows a specially constructed table traverse indicator, oscilloscope and microchromometer within the field of a 16 mm. Kodak Ciné Special Camera.

Two enlarged frames of the ciné film are given in Fig. 5(a) and (b). From the film analysis are determined :

1. spindle speed, free running;
2. spindle speed successively along the length of workpiece;
3. table speed free running in each direction;
4. table speed successively along the length of the workpiece;
5. serial number of the run.

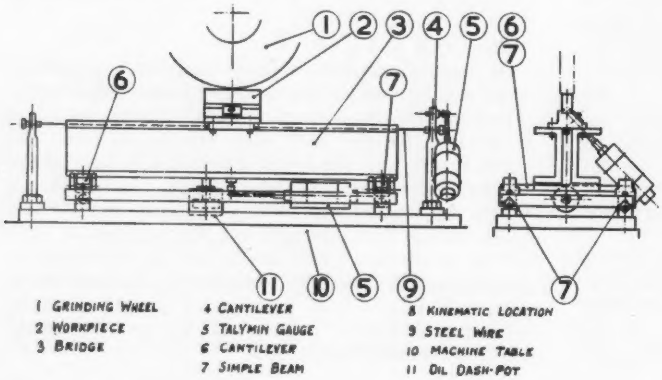


Fig. 3. Diagrammatic view of the dynamometer.

spindle temperature

The wattmeter reading, when it has assumed a steady minimum value during free running, gives an indication of stable running conditions of the spindle drive.

In addition, the maximum stable temperature of the wheel spindle is essential to ensure constant condition of clearances in the spindle bearings and of oil viscosity. To observe when these conditions obtain a thermometer is fitted in the spindle cover plate, engaging with the fixed ring of the spindle front bearing.

cutting fluid

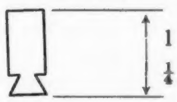
The cutting fluid used was soluble oil, " Solvac Clear " by Vacuum Oil Company Limited, in the proportion 1 in 48 parts of water at the rate of 1.2 gallons per minute.

Wheel Dimensions

Outside Diameter	8 in.
Width	$\frac{3}{4}$ in.

Work Dimensions

Width	$\frac{1}{2}$ in. $\pm$ 0.001 in.
Length	3 in.
Section	



variables

Grinding wheels were supplied and specially graded by Universal Grinding Wheel Company Limited, to ensure that the grade spacing was uniform. An exact record of the characteristics of each wheel has been kept by the manufacturers for reference purposes should any of the results prove this to be necessary.

The standard wheel adopted was WA. 46 J.V.

Comparisons were made between :

grades of hardness	G, J and M.
sizes of grit	36, 46 and 60.
abrasives	W. (Al_2O_3) and C(Si.C).

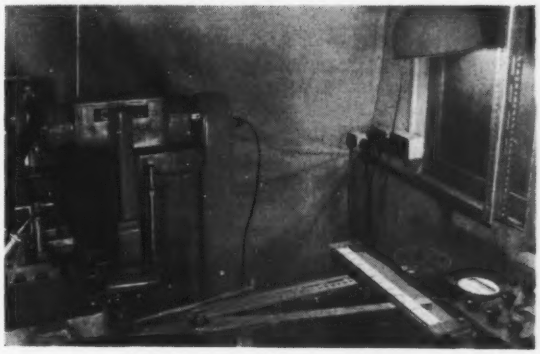


Fig. 4. Wheel and work speed indicators.

work material

The material used, supplied by Arthur Balfour and Company Limited, Sheffield, was " N.S.S.3 " oil hardening non-shrink steel, C 1.0%, Si 0.3% and Mn 2.0%, heat treated as follows :-

Hardened and stress relieved	800 V.P.H. $\pm$ 2%
Hardened and tempered	200 V.P.H. $\pm$ 2%
Cast iron, specially prepared low alloyed iron by the Department of Metallurgy, University of Birmingham	195 B.H.N. $+3\%$ -2%

wheel speed

A nominal speed of 2,400 r.p.m., standard for this machine, was unchanged throughout the experiment.

Spindle driving motor is :

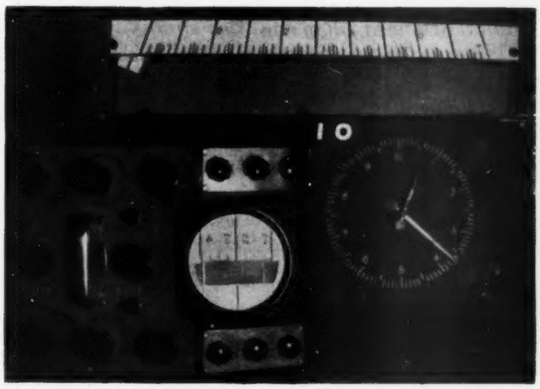
0.9 H.P. (Cont.) at 1,420 r.p.m.

table speed

The full range of the hydraulic table-traverse drive is covered by the following selected speeds.

8 — 15 — 24 — 36 ft. per min.

The required speed is set by reference to a Smith's Portable Tachometer. Actual table speed is determined from the film analysis.



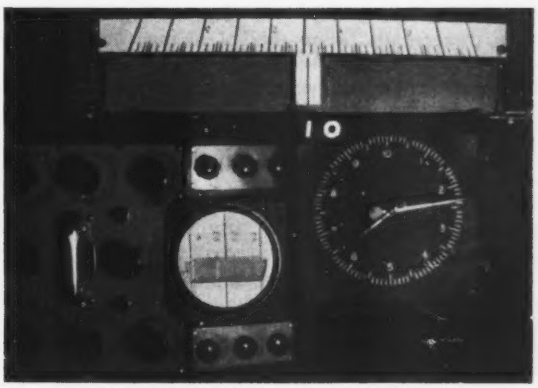


Fig. 5(a) (left) and Fig. 5(b) (right). Ciné frames — two frames of the same stroke.

planning the sequence of the experiment

Reliability trials were first carried out to test the response, resilience and repetition of the dynamometer; the durability and consistency, under continuous running, of the electrical measuring equipment; and to determine suitable film speeds, lens aperture and shutter openings for the cine-camera.

The dynamometer was calibrated for different magnifications of the Talymin Amplifier, using dead weights up to 20 lb. for the vertical and horizontal components.

For the vertical loading the weights were positioned on the workpiece. The horizontal loads were attached to a wire passing over a pulley, mounted on a bracket fixed to the table, and connected to the work holding fixture on the dynamometer. The possibility of pulley friction interfering with load was checked by introducing a tension spring balance in the horizontal portion of the wire.

The pen displacements of the Taylor Hobson Rectilinear Recorder were observed to be linear and consistent for rising as for falling loads.

effect of work temperature on load calibration

It was observed during a trial run, when dry grinding, that there was a shift of the zero setting on the vertical load recording tape. This was found to be due to the rise in temperature of the dynamometer bridge, resulting from the heat generated in the workpiece by grinding.

With the thermometer strapped to the web of the bridge there proved to be no rise in temperature when wet grinding, during extended trials, and no shift of the zero setting.

During the pilot runs the initial peak in the overall force pattern was first observed. This was found to respond to the method of wheel dressing and, when this was standardised as described below, consistent repetition of the initial peak was obtained.

diamond truing

Wheel dressing by a sharp pointed pyramid diamond was effected by normal speed of cross traverse of the table with a depth of cut, at each pass, of 0.3×10^{-3} in. This was repeated until the blackened track on the wheel, developed during the previous run, was removed. Then followed a reduction of the feed to 0.1×10^{-3} in. with a very slow cross traverse and a number of further traverses to spark-out. The wheel was considered satisfactory following this technique, providing it had a velvet touch when tested with the finger.

A constant flow of water on to the point of contact of the diamond was maintained throughout the dressing operation. It was imperative that wheel dressing took place only when the standardised spindle condition had been attained.

pilot run

A final pilot run, of approximately 320 cycles, was made with a continual recording of the vertical and horizontal forces and from this it was planned that a test run be divided into groups of 16 cycles. A cycle is a pair of consecutive strokes, one in each direction. During the first group the forces would be recorded for all cycles; this would then cover the initial peak. In succeeding groups only the forces of the last five cycles would be recorded and, during the last cycle of these five, a film record of the table and wheel speeds would be made. This plan was found to provide sufficient data to enable a clear analysis of the test run to be made. Duration of a run would be of the order of 12 groups providing stable conditions were obtained.

It was to be expected that the conditions during certain runs would approach the limits of endurance of the equipment. Therefore, when signs of approaching distress appeared, recordings were made as close as possible to the limiting conditions before stopping the run.

standardised conditions for the equipment

spindle driving motor

After 30 minutes of running, the power consumption had reached a minimum value on the wattmeter between 160 - 180 watts per phase.

spindle bearings

The temperature of the front bearing had, in this time, attained a maximum between 135° - 140°F.

hydraulic traverse

During this period the table traverse had been run at slow speed to ensure stable temperature conditions and to free the oil system of air.

electronic circuits

Fifteen minutes' warming-up time was found to be sufficient for the electrical equipment except that the insertion of the tachometer probe, into its working position, was delayed until immediately prior to a recording.

This latter precaution became necessary due to the proximity of the heat of the spindle bearings. With the probe permanently in position there would eventually develop, due to temperature rise, an abrupt failure of the probe.

stroboscope

This susceptibility of the probe made it desirable to record, by means of a stroboscope, the minimum and steady running speeds of the spindle for both up and down grinding during the filming of the particular cycle. This provided a check on the oscilloscope reading.

commencement of a run

When the above conditions had been obtained with the selected wheel and workpiece in position, the appropriate table speed and wheelhead feed determined, the run commenced with four to six unrecorded working strokes before the force recorders were switched on for the first 16 cycles.

This ensured that the workpiece was straight and parallel with the table traverse and also reduced the effect of instability of the freshly dressed wheel.

RESULTS

general

Table II gives the data of the runs of this sequence of experiments. The second number in column I refers to the chronological serial number of the run and it will be seen that certain runs were repeated to check the repeatability of the figures obtained. This

TABLE II — DATA OF THE RUNS

(1) No. of run		(2) Material of Workpiece	(3) Nominal Table Speed	(4) Depth of cut	(5) Grinding wheel	(6) Diameter of wheel	(7) No. of Groups in Run
Ref. No.	Chron. order.		f.p.m.	10^{-3} in.		in.	
1	1	ST.800 VPH	8	0.1	WA 46 JV	7.98	5
2	57	,,	8	0.1	WA 46 JV	7.42	5
3	53	,,	8	0.1	WA 36 JV	8.05	4
4	52	,,	8	0.1	WA 60 JV	7.98	4
5	10	,,	8	0.3	WA 46 JV	7.75	4
6	2	,,	15	0.1	WA 46 JV	7.96	10
7	58	,,	15	0.1	WA 46 JV	7.40	9
8	54	,,	15	0.1	WA 36 JV	8.04	9
9	51	,,	15	0.1	WA 60 JV	7.99	11
10	47	,,	15	0.1	WA 60 JV	8.04	4
11	31	,,	15	0.1	WA 46 GV	7.83	3
12	46	,,	15	0.1	C 46 JV	7.96	7
13	9	,,	15	0.2	WA 46 JV	7.80	9
14	6	,,	15	0.3	WA 46 JV	7.86	6
15	30	,,	15	0.3	WA 46 GV	7.88	6
16	3	,,	24	0.1	WA 46 JV	7.93	10
17	59	,,	24	0.1	WA 46 JV	7.38	9
18	55	,,	24	0.1	WA 36 JV	8.03	11
19	50	,,	24	0.1	WA 60 JV	8.00	10
20	8	,,	24	0.3	WA 46 JV	7.84	10
21	4	,,	36	0.1	WA 46 JV	7.90	10
22	60	,,	36	0.1	WA 46 JV	7.36	12
23	56	,,	36	0.1	WA 36 JV	8.02	11
24	49	,,	36	0.1	WA 60 JV	8.02	10
25	48	,,	36	0.1	WA 60 JV	8.03	8
26	32	,,	36	0.1	WA 46 GV	7.80	7
27	33	,,	36	0.1	WA 46 MV	7.98	7
28	5	,,	36	0.3	WA 46 JV	7.89	12
29	29	,,	36	0.3	WA 46 GV	7.88	8
30	61	ST.200 VPH	15	0.05	WA 46 GV	7.77	8
31	15	,,	15	0.1	WA 46 JV	7.60	9
32	26	,,	15	0.1	WA 46 GV	7.95	6
33	37	,,	15	0.1	WA 46 MV	7.94	8
34	66	,,	15	0.2	WA 46 GV	7.66	7
35	11	,,	15	0.3	WA 46 JV	7.71	10
36	27	,,	15	0.3	WA 46 GV	7.92	5
37	62	,,	24	0.05	WA 46 GV	7.75	7
38	65A	,,	24	0.2	WA 46 GV	7.67	10
39	13	,,	24	0.3	WA 46 JV	7.68	8
40	63A	,,	36	0.05	WA 46 GV	7.61	7
41	14	,,	36	0.1	WA 46 JV	7.63	8
42	42	,,	36	0.1	WA 46 GV	7.97	11
43	38	,,	36	0.1	WA 46 MV	7.92	8
44	64A	,,	36	0.2	WA 46 GV	7.69	11
45	12A	,,	36	0.3	WA 46 JV	7.70	6
46	28	,,	36	0.3	WA 46 GV	7.90	8
47	16	CI.195 BHN	15	0.1	WA 46 JV	7.58	7
48	23	,,	15	0.1	WA 46 GV	7.99	6
49	41	,,	15	0.1	WA 46 MV	7.90	4
50	42	,,	15	0.1	C 46 JV	8.01	9
51	19	,,	15	0.3	WA 46 JV	7.48	7
52	22	,,	15	0.3	WA 46 GV	8.01	9
53	20	,,	24	0.3	WA 46 JV	7.48	8
54	17	,,	36	0.1	WA 46 JV	7.55	10
55	24	,,	36	0.1	WA 46 GV	7.98	9
56	43	,,	36	0.1	C 46 JV	7.99	13
57	21	,,	36	0.3	WA 46 GV	8.04	3

proved satisfactory even when the second run occurred some days after the first.

Wheelspeeds and forces were analysed from the film and tape recorder respectively and similarly tabulated.

table speeds

From the film, analysis of the table speeds revealed that the mean speeds, during grinding, varied slightly from the nominal setting and that this variation was greater for up grinding than for down grinding.

The deviation ranges for the various table speeds are shown in Table III.

TABLE III

$\frac{V}{M \cdot N}$	Range of Average	
	Up	*Down*
f.p.m.	%	%
8	–1	+4
15	–4	+3
24	–5	+1
36	–6	+4

Table speed in up-grinding was, in general, 7% lower than in down-grinding.

These figures are for actual table speeds under the grinding load and when it was realised that the speeds in up-grinding differed from those in down-grinding, it became necessary to determine the zero load speeds. These proved, from their similarity with the speeds under load, that the speeds in the two directions differ mainly as a result of the hydraulic mechanism of the machine. The results also exposed the fact that the speeds varied from run to run and so it became necessary to examine, more closely, whether the direction of the wheel movement relative to the table movement had any effect on the table speed.

For this purpose comparisons were made of table speeds with the wheel on and off the workpiece during the same run; it was shown that the conditions of grinding, heavy or light, resulted in variations in the work speeds under and off the wheel.

However, the differences are small and of no importance where grinding loads, etc., *versus* table speeds are concerned, but it is of interest to note that it occasionally arises in down-grinding where the work speed under the wheel is higher than the free running speed.

The ratio of the two speeds, loaded and free, were :-

in up-grinding 0.85 - 1.00 with average 0.9., and
in down-grinding 0.98 - 1.10 with average 1.02.

spindle speed

Nominal spindle speed was 2,400 r.p.m.; the actual values recorded at the commencement of each run varied between 2,380 and 2,440 r.p.m. Accuracy of reading was ±5 r.p.m. due to fluctuation of the oscilloscope beam as a result of external disturbances.

The differences in wheel speeds appeared to be inconsistent in both direction and magnitude. However, examination reveals that the significant factor, determining the drop in wheelspeed, is the force involved in the grinding process.

In Fig. 6 fall in wheel speed is plotted against the tangential force F_T for all runs; here the manufacturer's torque slip curve is included. This curve conforms closely to the plots within the grinding conditions for which the machine was designed and equipped. Under the more severe conditions, inevitable during experiments of this nature, it is evident that some loss of wheel speed results from belt slip and in the extreme condition this amounts to 20%.

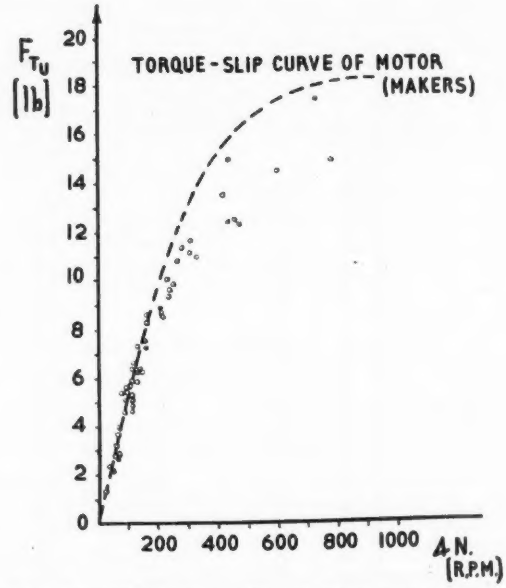


Fig. 6. Tangential force — drop of wheel speed 'upcut'.

The pattern of slow-down of spindle speed under load, as found by film analysis, is shown in Fig. 7, for up- and down-grinding of the same cycle.

The wheel slows down to a steady minimum and then increases rapidly the moment the wheel leaves the workpiece.

The form of the slow-down curve is one of deceleration of the rotating mass of rotor and wheel-spindle under the retarding force of grinding.

The wheel diameters ranged between 8.05 and 7.36 in. and the surface speed of the wheel ranged between 5,050 and 3,300 f.p.m. up-grinding and 5,030 and 3,480 f.p.m. for down-grinding.

depth of cut

The values of the depth of cut used during the experiment were 0.05, 0.1, 0.2 and 0.3 $\times 10^{-3}$, and they operated at each end of the table stroke. With higher values than this, the wheel stalled due to the excessive forces involved.

chip thickness

The accepted formula, quoted earlier, was used to calculate chip thickness; the minimum value was found to approach the critical chip thickness of 28 $\times 10^{-6}$ as determined by Backer, Marshall and Shaw [4].

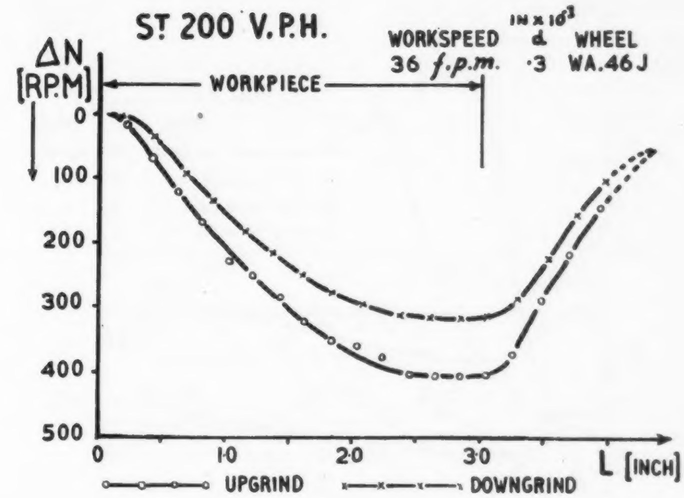


Fig. 7. Drop of wheel speed in grinding.

forces

There is a consistent pattern of change in forces during a normal run. This is shown in Fig. 8, where it is divided into four regions :-

(i) an unstable region where the forces rise to a peak (the elasticity of the machine and dynamometer is accommodated and the depth of actual cut finally equals the down feed) and then fall to a steady value as the dulling effect, produced by wheel truing, wears off;

(ii) a region of stable grinding condition where forces and speeds are constant and heat is in equilibrium;

(iii) in this region there is a progressive build-up of forces and power reflecting the reactions of the wheel to the particular combination of work speed, depth of cut and work material.

Wheel grits become dull, overheating may develop and grinding becomes progressively inefficient;

(iv) the rate of increase of the forces becomes less, there is evidence of vibration and as this develops the magnitudes of the forces commence to fall, as observed by Landberg [7].

No means of measuring vibrations had been provided, but their presence was indicated on the force recordings on the tapes. These vibrations were substantial under severe grinding conditions such as in the run No. 52 where the regions (ii) and (iii) never developed. It became necessary to stop the run, solely because of vibrations and not because of high forces; forces were falling rapidly.

The characteristics of the changes in the forces as grinding continued were similar for both up- and down-grinding and for the vertical and horizontal components, i.e., F_N and F_T.

That the instability evident in Region I is concerned with the effect of a dull wheel, resulting from the method of wheel dressing, was emphasised during a severe run (No. 45). In the first stage of the run the forces continued to rise rapidly until the wheel stalled. The wheel was redressed and a second attempt made, but this time the actual run was preceded with a period of lighter grinding. When the actual run took place, steady conditions were reached with a peak hardly discernible.

A preliminary investigation was made into the effect produced on the face of the wheel by the pro-

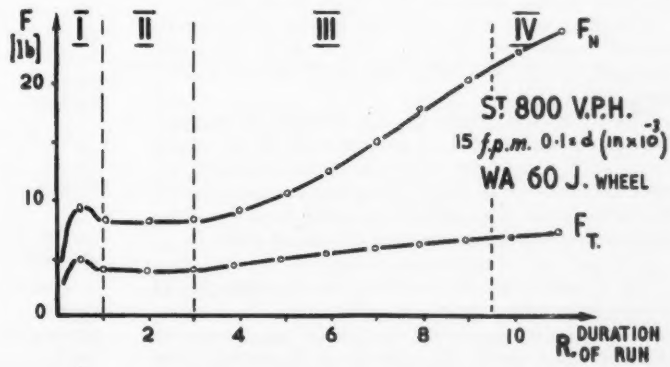


Fig. 8. Pattern of forces in grinding.

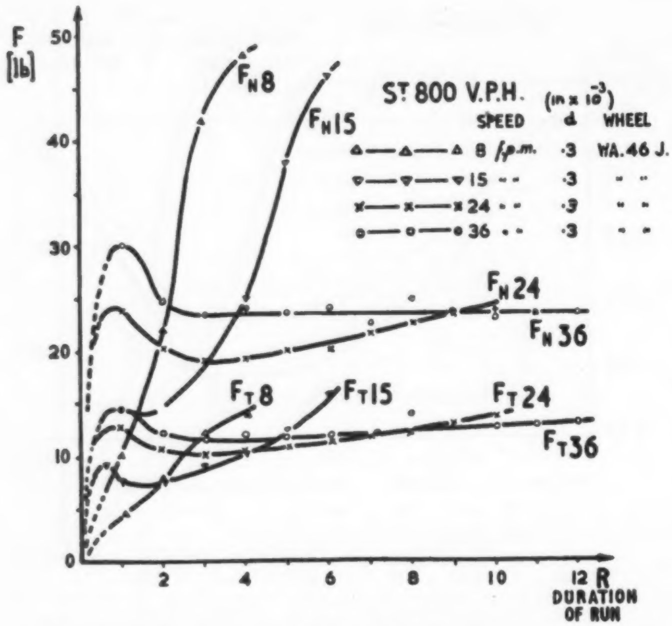


Fig. 9.
Forces for various table speeds.

cess of truing. The practice of rolling the wheel over a plate glass coated with carbon [4] was followed, first with the wheel immediately following truing and then by the same wheel after it had run approximately 300 cycles under steady load conditions.

As pointed out in Reference [4], the grit contact areas can be expected to be larger than the grit due to pick up. Therefore to ensure a fair comparison the tracks of the two conditions of wheel were made alongside each other on the same piece of smoked glass.

For the wheel "as dressed" the areas are of considerable size, and, by comparison with the worn wheel track, can be assumed to include more than one grit. This suggests that in addition to the grit having a zero clearance due to dressing [9] the surrounding bond is trued flush with the grit. In this condition with the bond shrouding the grit, the wheel will be "loaded", forces will be high and will continue so until the shrouding breaks down, leaving the edges of the grit unsupported. The grit then sharpens as the unsupported edges break away.

Comparisons of forces for the various table speeds can be made from Fig. 9. In all these cases the standard wheel, WA 46J, was used on the harder steel, 800 V.P.H.

The scale of R represents the number of readings taken, i.e., the number of groups each of 16 cycles. Thus, with a constant depth of cut this axis represents the volume of metal removed independent of the table speed. This affords a better basis for comparison than would result from the use of time.

The pattern of forces conforms to the standard of Fig. 8, except for the lowest speed where Region II is represented by a point of inflection.

Forces at the commencement of the runs are lower at lower table speeds, but, as the runs continue, the reaction of the wheel, to the conditions, is reflected in an upward trend of the forces which is steeper for the lower speeds. Ultimately, the forces for each overtake the forces of the next higher speed and even the forces of the highest speed are still climbing, though only slowly, after 384 strokes at 0.0003 in. feed per stroke.

It is also worthy of note that F_N increases at a faster rate than F_T except in the case of 36 f.p.m., where F_N remains constant after the third group.

The effect of work hardness on the forces becomes involved with wheel hardness and work speed. Some effects of these relationships are indicated in Fig. 15; the hardness of the wheel proves to be of great importance with regard to the effect of workspeed and although forces fall as the wheel gets softer, the rate of fall is more dependent on workspeed than on hardness of material.

In the relationship between the forces in up-grinding and down-grinding, it will first be necessary to point out, as did Outwater and Shaw [6], that the normal forces are downwards in both up- and down-grinding which is contrary to that experienced in milling.

In grinding, the ratio of chip thickness to its length, $\frac{t}{l}$, is so small that the cutting forces, as far as the chip grit interface is concerned, remain substantially horizontal in both directions of grinding.

Therefore, the combined effect of the vertical components on the chip grit interface and that due to peripheral rubbing of the grit on the body of the work, is a downward force and there is no tendency

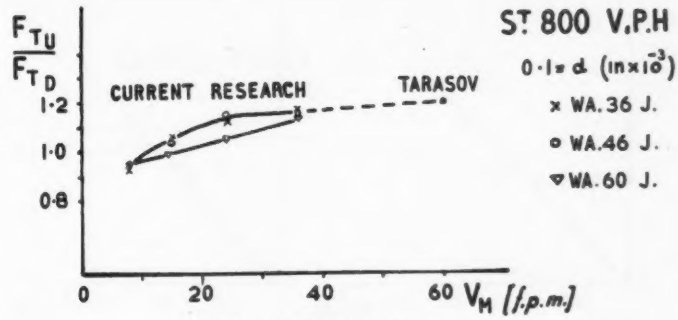


Fig. 10. Ratio up-down of tangential forces for various table speeds.

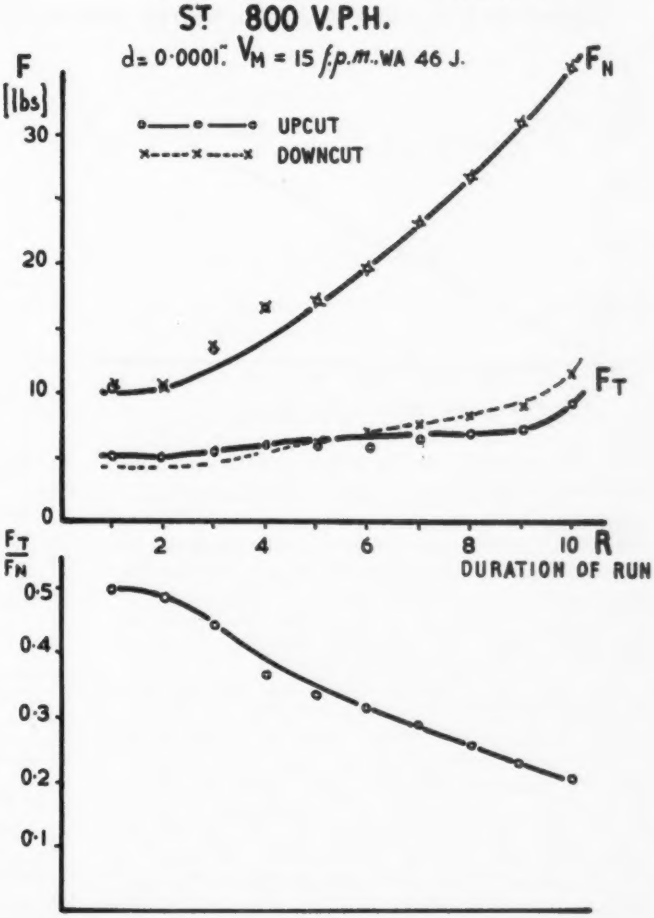


Fig. 11. Pattern of forces and corresponding coefficient of grinding.

to lift the work as in a conventional milling operation.

The ratio of forces in up-grinding to forces in down-grinding varies with table speed. As the speed falls it becomes less than unity and the table speed at which this occurs, according to the results of these experiments, is approximately 10 f.p.m. However, as shown in Fig. 10, the 60 grit wheel crosses the boundary at 15 f.p.m.

In Reference 1, this ratio was found to be unity, but this was for the ½ in. long workpiece and a maximum table speed of 16 f.p.m. Tarasov claimed that at 60 f.p.m. upcut forces would exceed downcut forces by 20%. Extrapolation of the figures of the current research are shown, in Fig. 10, to coincide with the value put forward by Tarasov.

The force values for such determinations as the above ratio, and other comparisons in this work, have been taken in Region II where possible, and at the point of inflection where steady force conditions did not develop.

This observation is important in many of the comparisons made and this is well illustrated in Fig. 11, where at 15 f.p.m. the downcut force overtakes the

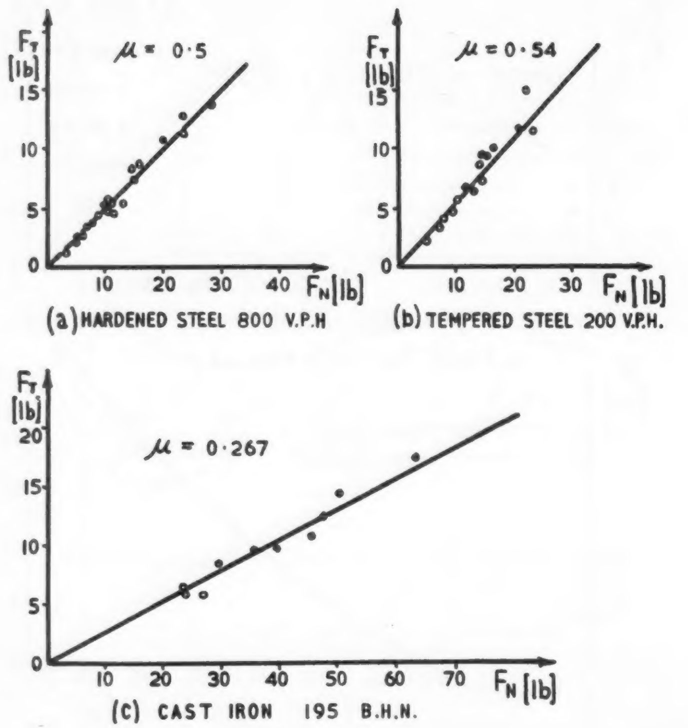


Fig. 12. Coefficient of grinding for various materials.

upcut force as the run develops between the fifth and sixth group.

coefficient of grinding

In Figs. 12(a), (b) and (c) this ratio is plotted for the three different materials used; the figures used are the mean values for stable conditions for every run.

The ranges of this coefficient for different materials using the standard grinding wheel — WA 46J — are as shown in Table IV.

The difference between the values for the two directions is mainly the result of change in the tangential force, as the normal forces for this grade of wheel remained substantially the same in each direction, as shown in Fig. 11. The coefficient varies during the course of the runs, particularly where Region II is of short duration, i.e., on the slower table speed and with the harder wheel. The trend is for the value of the coefficient to fall as the grit dulls and the forces increase. This is shown in Fig 11.

For the higher speeds of table traverse the coefficient of grinding is higher. This could be observed from Fig. 9, for a 46J wheel; it is shown more clearly plotted against various values of V_M in Fig. 13 for a 60J wheel.

In Fig. 14, this upward trend is shown to be similar but independent of grit size.

Marshall and Shaw [1] suggested that the higher the coefficient of grinding the more efficient was the grinding operation. On this basis the current research indicates that the grinding operation becomes more efficient at higher work speeds, and that this increase in efficiency is only slightly dependent upon grit size.

The effect of grit size on the coefficient of grinding is found to be similar in value to those obtained by M.I.T. [1].

For the aluminium oxide wheels they are given in Table V.

TABLE IV

MATERIAL	F_{T_U}/F_{N_U}	F_{T_D}/F_{N_D}
St. 800 V.P.H.	0.47 - 0.55	0.38 - 0.50
St. 200 V.P.H.	0.48 - 0.70	0.48 - 0.52
Cast Iron	0.23 - 0.30	0.20 - 0.25

TABLE V

Grit Size	*Current Results*		*M.I.T. Results*	
	F_{T_U}/F_{N_U}	F_{T_D}/F_{N_D}	F_T/F_N	*Coefficient of Friction*
36	0.53	0.46	0.57	0.42
46	0.51	0.42	0.52	0.42
60	0.53	0.48	0.52	0.47

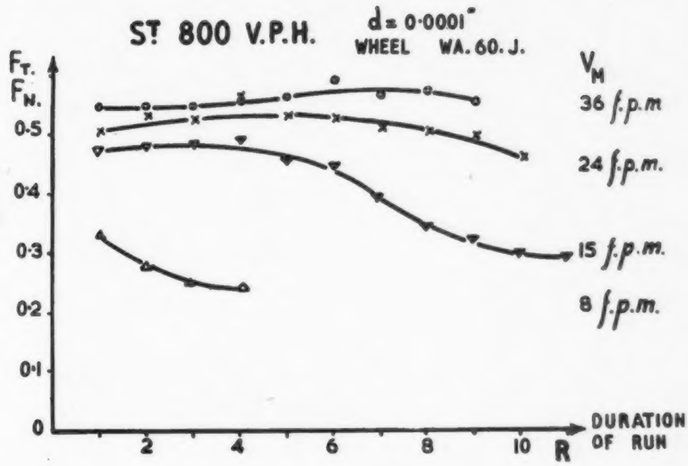


Fig. 13. Coefficient of grinding for various table speeds.

specific energy

The energy required to remove one cubic inch of metal is defined as the specific energy of metal removal and is calculated using the formula :-

$$U_S = \frac{V_W \quad F_T}{V_M \quad b.d.} \text{ (in. lb. per cubic in.)}$$

V_M = surface speed of work in ft. per min.

V_W = surface speed of wheel in ft. per min.

b = width of work in inches.

d = depth of cut in inches.

In the determination of U_S the actual values of V_W and V_M, as analysed from the films, are used and not the nominal speeds.

The values of U_S obtained extend over a very wide range, specifically from 8.23 to 73.2. 10^6 in.-lb. per cubic in., and it becomes necessary to assess their significance strictly in relation to the conditions under which they were obtained.

Providing other factors remain constant, $U_S \propto F_T$.

Therefore, previous comparisons, in this work, of F_T for changes in depth of cut or work speed, etc., will correspond to comparisons of U_S with those particular variables.

Specific energy has been used successfully in metal cutting operations as a basis for the determination of efficiency of an operation.

Its main virtue is that, in combining work speed and depth of cut, comparisons are possible between all combinations of these two variables. This leads to a reasonably constant value of U_S for turning and milling under certain prescribed cutting conditions.

However, earlier research workers in grinding 4, 5, 6, 15, 18, 21 have maintained that chip thickness is the main criterion of specific energy.

From the adopted formula for the determination of chip thickness it will be seen that

$$t \propto V_M^{\frac{1}{2}} d^{\frac{1}{4}}$$

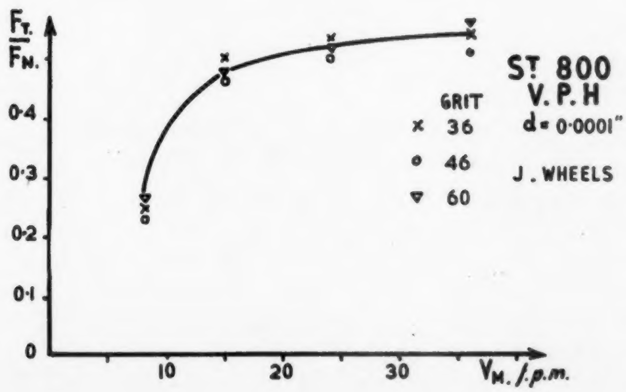


Fig. 14. Coefficient of grinding — table speed for various wheel grit sizes.

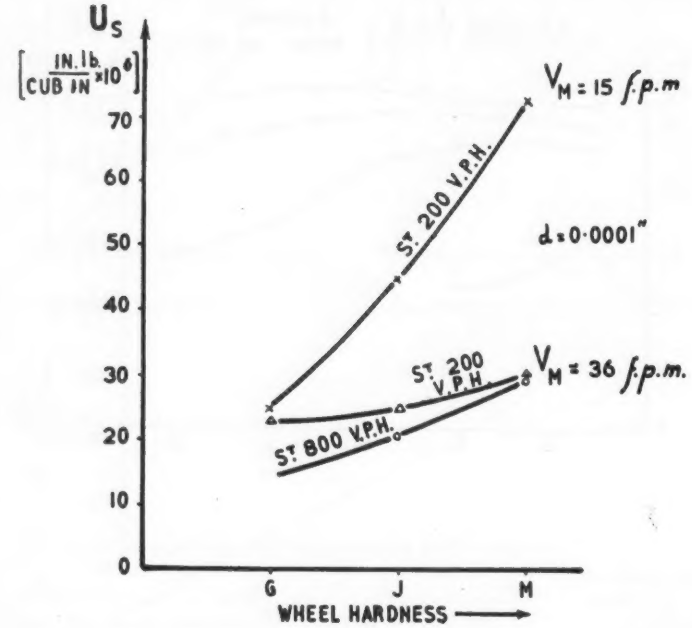


Fig. 15. Specific energy — wheel hardness — work hardness and work speed.

Thus there are different values of V_M and d for each value of t.

Also from the formula for U_S

$$U_S \propto \frac{I}{V_M \quad d}$$

Thus there could be a different relationship between U_S and t depending upon whether t varies as a result of a variation of "V_M" or of "d".

To explore this possibility U_S is plotted against t in Fig. 17(a) and (b) for two different depths of cut in each case and for three different table speeds.

In general U_S decreases as t increases.

However, in both graphs the change in U_S for an equivalent change in t is much greater when it results from a variation of d than from a variation of V_M.

For example, referring to A :-

For an increase in chip thickness " t " of 28% :-
with " d " constant at 0.0001 in. U_S falls 12%

with V_M constant at 24 f.p.m., U_S falls 47%

A comparison of A with B is a comparison of the effect of the grade of the wheel on the specific energy. In B, with the softer G wheel and the finer depth of

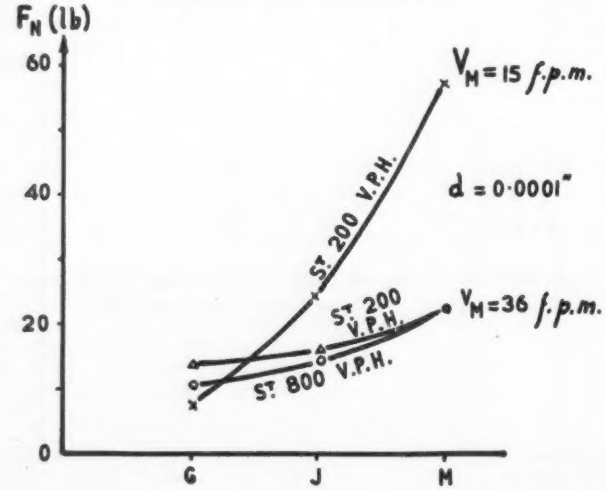


Fig. 16. Normal force — wheel hardness — work hardness and work speed.

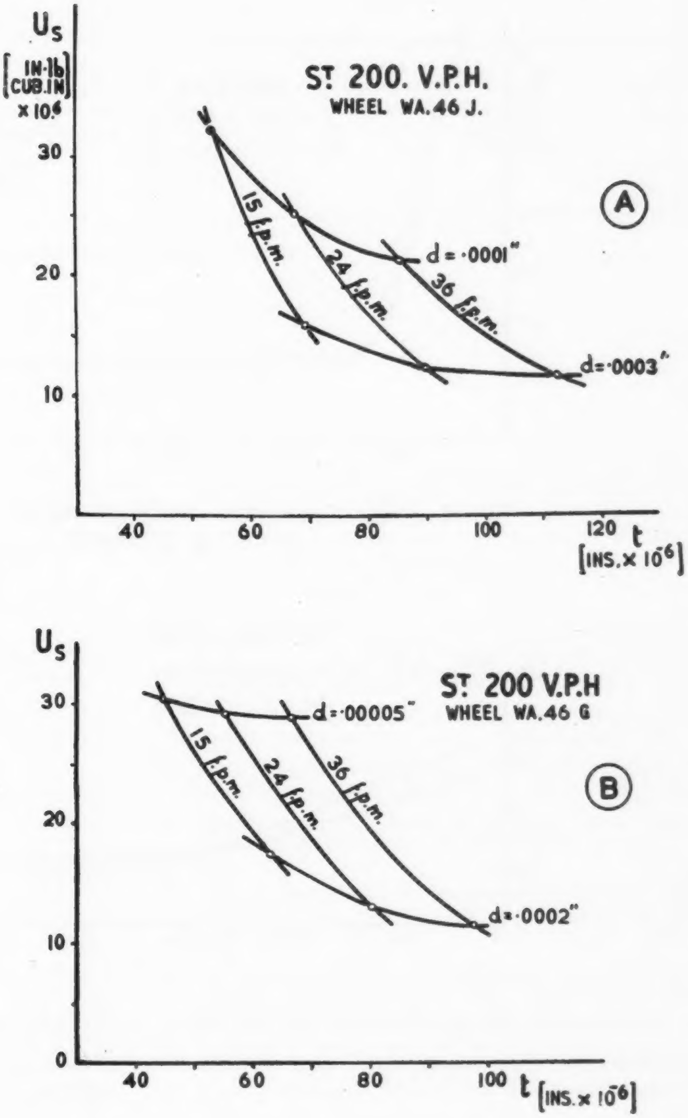


Fig. 17. Specific Energy U_S—Chip Thickness t. With α Constant and with V_M Constant.

cut, there is very little change in specific energy with change in work speed, while at A, with the harder wheel, there is greater change in U_S as the work speed changes.

This is again illustrated in Fig. 15, where U_S is almost the same for a G wheel at 15 and 36 f.p.m. and yet for the M wheel U_S increases two-and-a-half times as the work speed decreases from 36 to 15 f.p.m. At 36 f.p.m. there is only slight difference in specific energy between the two *hardnesses of material* using the M wheel but the softer G wheel has a *lower* specific energy for the *harder* material.

In Reference 15, the authors, Reichenbach, *et al,* in their reply to Boston, "agree that chip thickness alone is not a reliable method for predicting power in grinding . . . specific energy may have several values depending upon conditions such as wheel sharpness, grinding fluid or type of grinding . . ."

No reference was made to the different means of arriving at the same chip thickness and, although the above results must await confirmation from a larger sample, there is evidence that chip thickness alone is not the sole criterion.

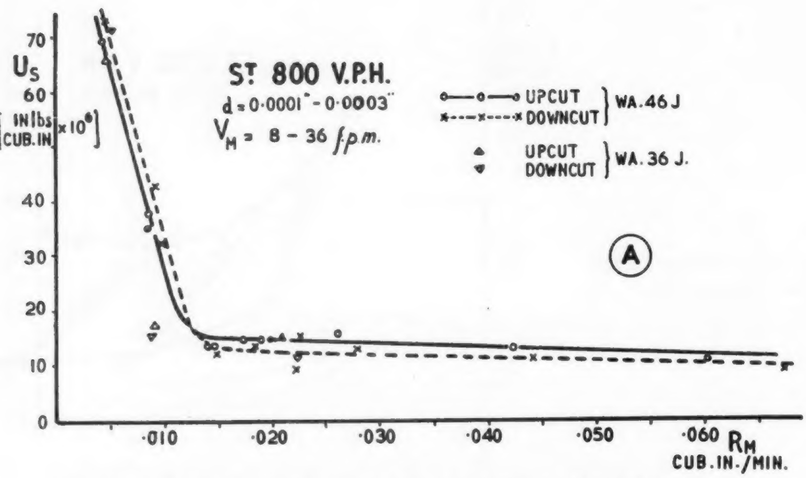
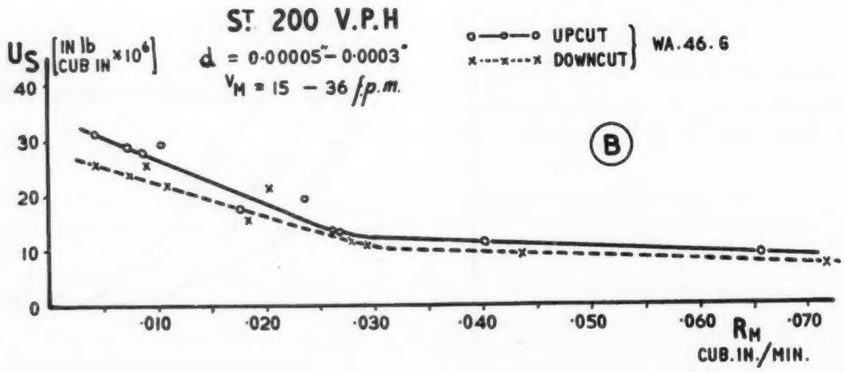


FIG. 18. SPECIFIC ENERGY – RATE OF METAL REMOVAL UPCUT & DOWNCUT



Current results do agree, however, with the earlier investigations, that U_S decreases with increase of chip thickness.

In Fig. 18 U_S is plotted against rate of metal removal which combines the two variables of depth of cut "d" and work speed V_M.

The two graphs A and B are again for the two grades of wheel J and G, respectively.

In both cases a straight line relationship is established until the rate of metal removal falls to a particular low figure and below this rate a drastic increase in U_S results. After this critical value of R_M the relationship continues to follow a straight line, but at a vastly different angle than for higher values of R_M.

The difference in behaviour between the two grades of wheel, as shown by the two graphs, is that for the softer G wheel (graph B) the critical value for R_M is higher than for the harder J wheel (graph A) and also the slope of the graph is much less, at B than A, as R_M falls below the critical value. There is an apparent change in the mechanism of grinding which occurs at a different point dependent upon the softness of the wheel. However, there is the other factor that the softness of the wheel also determines the maximum energy it can transmit.

There is an additional feature to be observed at A where the change of slope occurs. In this area the forces in down-grinding overtake those in up-grinding.

Thus from these two graphs A and B (Fig. 18), U_S is approximately constant (decreasing slightly with increase in R_M) above a critical value of R_M.

Fig. 18 will explain that the very wide range of values of specific energy results from two distinctly different conditions of grinding.

Under comparable conditions values of ^{U}S, when grinding with aluminium oxide wheels of different grit size, were slightly higher, but of similar tendency, as those found in previous experiments at M.I.T. [1] as shown in Table VI.

The silicon carbide wheels rendered higher values of ^{U}S than the aluminium oxide wheel.

TABLE VI

Grit Size	^{U}S (10^6 in.-lb. per cubic inch)	
	Current Results	*M.I.T. Results*
36	11.5	9.7
46	9.6	8.8
60	17.2	12.6

TO BE CONCLUDED NEXT MONTH

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THE DYNAMIC PERFORMANCE OF A MILLING MACHINE

by F. KOENIGSBERGER, D.Sc., M.I.Mech.E., M.I.Prod.E.,

and S. M. SAID, M.Sc.(Eng.), Ph.D.

Faculty of Technology, University of Manchester.

THE behaviour of machine tools under the effect of periodic or fluctuating forces has been the object of many investigations. Theoretical considerations assuming single or two degree of freedom systems as well as practical tests determining the behaviour of various members of a system, their inter-action and their connections, have added to the knowledge of the prevailing conditions.

The main purpose of a machine tool is, however, the production of workpieces, the shapes, dimensions, and surfaces of which are specified and whatever the vibration behaviour of the machine as such, the most important aspect from the point of view of the production engineer, is the influence of the vibration behaviour on the quality of the product, on the cutting conditions and the efficiency of production.

The present Paper describes an attempt to study some of the dynamic characteristics of a milling machine and to correlate the results with the surfaces produced during cutting operations.

Only vibrations of the machine structure (upright, table, knee and overarm) were studied. Torsional vibrations of the rotating members were not included as a short calculation showed that the large gear wheel keyed to the spindle closely behind the main bearing and acting as a flywheel reduced torque fluctuations to within permissible limits.

causes of vibration

(a) external sources

If a machine tool is not completely isolated from the main shop floor, the machines surrounding it, as well as other external causes, may transmit through the floor vibrations the seriousness of which will depend on the type and magnitude of the forces transmitted and on the foundation and the degree of insulation it provides.

Before the present investigation was started comparative measurements were taken on a jig boring machine in the Laboratory, which was located on a six feet deep insulated foundation block. Vibration amplitudes measured on the machine table due to the effect of excitation transmitted through the main floor reached 10 micro-in. at a frequency of approximately 7.5 cycles per second.

It was, however, observed that more serious vibrations occurred when an old planing machine installed in the Laboratory at a distance of about 15 ft. from the jig borer was running even without cutting. These vibrations which had a frequency of approximately 12.5 cycles per second had the following amplitudes :-

Vertical amplitude = 16 micro-in.
Longitudinal horizontal amplitude = 36 micro-in.
Transverse horizontal amplitude = 28 micro-in.

Although these amplitudes still appeared to be small their effects could be noticed on the surface quality of some work-pieces machined on the jig borer.

In order to eliminate floor effects on the milling machine under investigation this was placed on three $\frac{3}{4}$ in. thick pads of vibration insulating material. As a result, the maximum amplitudes of vibrations transmitted through the floor were found to be not more than 20 micro-in.

In view of the order of magnitude of the other vibration amplitudes measured during the investigation this was considered satisfactory.

(b) the driving system

The driving system excites forced vibrations due to the unbalance of rotating members, effects of the gearing and bearings, etc.

(c) the cutting action

Pulsations of the cutting force are caused by the inherent periodic variation of the chip thickness during the action of a milling cutter. The frequency of these pulsations is equal to the number of revolutions multiplied by the number of teeth of the cutter.

This investigation did not cover forced or self-excited vibrations caused by the process of chip formation itself.

The following parameters characterising the dynamic properties of the machines were investigated :-

(a) natural frequencies

Vibration amplitudes are highest at these frequencies and they would be critical even if the frequency of the external force was not exactly equal to but near a natural frequency, because high amplification still exists in that vicinity.

A harmonic force excites only the corresponding natural frequency in systems with linear characteristics. In the case of a milling machine the exciting cutting force is periodic, but far from harmonic. It can, however, be split into its harmonics, which contain the fundamental frequency together with its multiples of higher harmonics. Resonance will occur if the fundamental frequency or any of its higher harmonics coincides with a natural frequency of the machine.

The values of the natural frequencies can be estimated with high accuracy from the resonance peaks of experimental displacement — frequency curves. A knowledge of these values is essential from the points of view of :-

1. The designer of the machine tool who has to avoid natural frequencies which might lie near those of probable sources of excitation either in the driving system or in the range of the intended cutting conditions.
2. The user of an existing machine who has to avoid cutting conditions in the neighbourhood of the natural frequencies.

(b) damping

The total damping capacity can be determined from displacement frequency curves obtained experimentally for different modes of vibration of the machine.

(c) deformation shapes of vibrating members

As the milling machine is a system of many degrees of freedom, a corresponding number of modes of vibration would be expected, with different deformation shapes at each mode.

The geometrical shape of the deformed members of the machine at their maximum excursions during vibration can be determined by drawing the elastic curves of each natural mode.

The modes of the machine at other frequencies are also interesting, but the modes at the natural frequencies are preferably determined for the following reasons :-

1. The natural mode provides a picture of the deformation in the machine during probable resonance vibrations or chattering conditions, which would be the severest cases.
2. The graphical representation of a natural mode is simpler and more accurate than that occurring at any other frequency, because at a natural frequency the phase angle is 90° irrespective of the damping, and all points of a member will reach their maximum excursion simultaneously whatever the value of damping.

In actual practice, the parts of the machine have a certain degree of flexibility and play exists between the moving parts, e.g., the slides and slideways. The various members of the milling machine are thus not entirely constrained to move only in the operational directions (traverses, setting movements, etc.). The resultant translational vibrations of the members of the machine can, therefore, be expected to attain any direction in space and can be referred to three suitable co-ordinates.

The arbitrary but convenient choice of three co-ordinates, one vertical and two horizontal in the longitudinal and transverse directions of the table, provides three sets of directional natural frequencies for the machine at any configuration.

Owing to the great number of natural frequencies obtained for the machine when tested at different configurations, it appeared reasonable to select the most serious values for the determination of their deformation curves.

In the present case the modes obtained from the resonance curves under a dynamic load of 20 lb. were considered serious if their equivalent static deflection under a load of 120 lb. exceeded 0.001 in. or 25 microns.

experimental work — measuring and excitation equipment

(a) measuring equipment

Although an ideal transducer for measuring different types of vibrations does not appear to exist the electro-dynamic pick-up used (Fig. 1) was found to satisfy the following requirements :-

1. convenient mounting at most points of the machine;
2. suitable frequency response in the testing range;
3. possibility of direct calibration;
4. suitable sensitivity for recording with a pre-amplifier.

The output signal from the vibration pick-up was fed to the amplitude calibration unit (Fig. 1). This included :-

(a) an integration circuit to give displacement;
(b) a differentiation circuit to give acceleration;
(c) an amplitude calibration circuit.

A pre-amplifier was found necessary for recording or monitoring small signals.

An electronic wave analyser was used for determining the frequency and amplitude of the harmonic component of the complex waveforms of long duration encountered during the idle running tests.

The main unit could be tuned to any frequency between 19 c.p.s. and 21,000 c.p.s. and the amplitudes could be read directly on the meter which could be calibrated in vibration units (Fig. 1). A low frequency modulating unit enabled the wave analyser to be used for the analysis of low frequencies from 2 c.p.s. to 20 c.p.s.

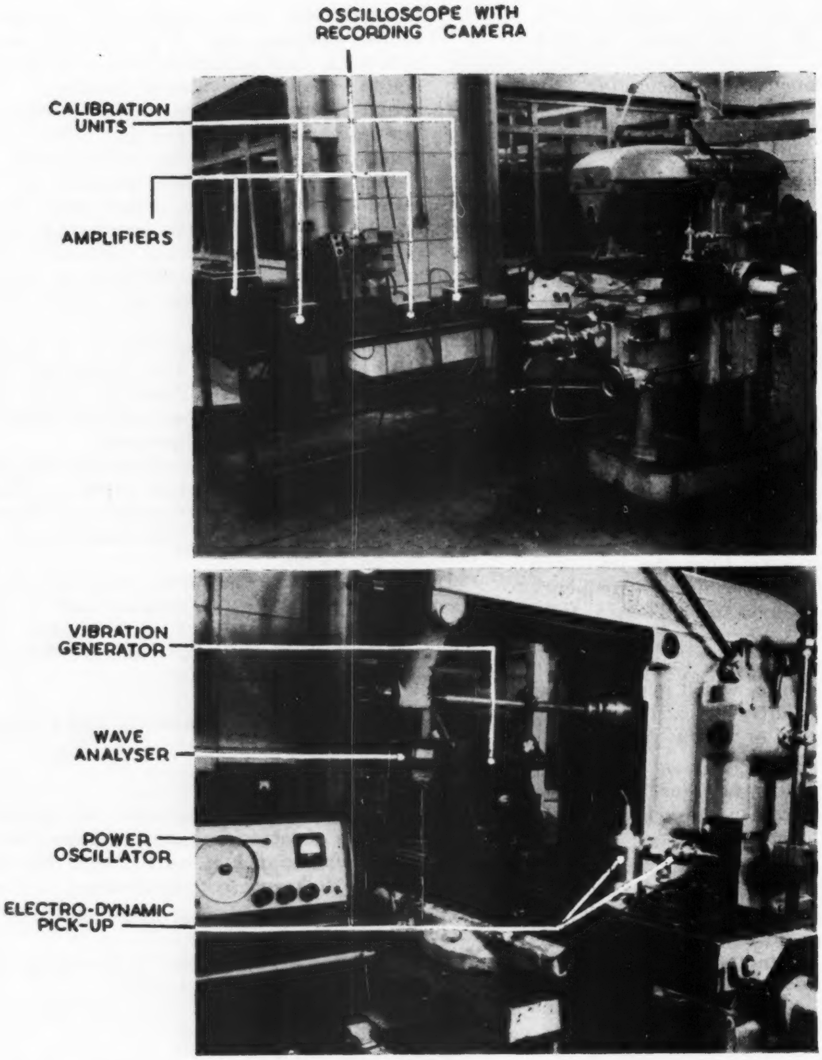


Fig. 1.

As the available A.C. oscilloscopes have usually a minimum frequency response of 20 c.p.s., a D.C. oscilloscope was used for recording signals of frequencies lower than 20 c.p.s.

(b) excitation equipment

The electro-dynamic vibrator (Fig. 1) was chosen because of its

(i) weight and size;
(ii) frequency range;
(iii) ease of frequency control;
(iv) harmonic exciting force;
(v) simple adjustment of the force amplitudes.

The vibrator was driven by a harmonic current delivered from a power oscillator with an adjustable frequency range of 10 - 10,000 c.p.s.

The excitation force was applied in a plane normal to the spindle axis between the arbor and the machine table at an inclination of 45° to the table, thus producing horizontal and vertical excitation in one setting of the generator. At the same time, the vibration measurement in one direction would include the simultaneous effect of the two components of the exciting force.

The vibration generator was rigidly clamped to the table. The driving spindle was attached to the machine arbor through a rigidly clamped connecting head.

The added mass of the connecting head was considered to be equivalent to that of the cutter and it could, therefore, be assumed that the elastic behaviour of the system was not greatly different from that encountered under actual working conditions.

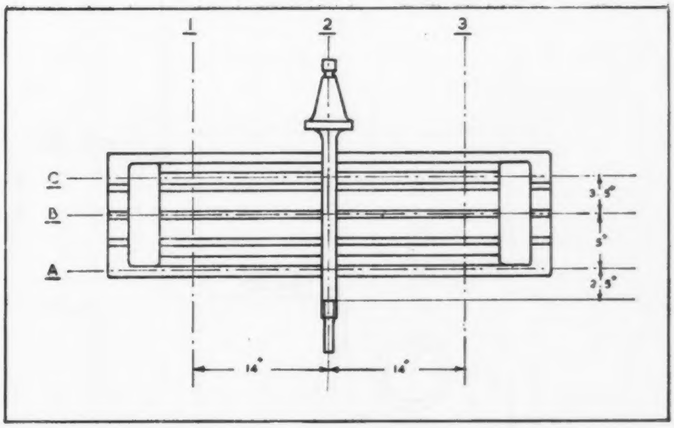


Fig. 2.
Excitation configurations.

the machine configurations

The vertical position of the knee was determined by the height of the vibration generator. This happened to coincide approximately with the mean position of the vertical working configurations.

One longitudinal central and two extreme positions of the table were tested at three transverse positions, as shown in Fig. 2.

In order to eliminate discrepancies between the values of natural frequencies obtained during excitation and those obtained during cutting operations, the excited members of the machine were coupled in the same manner as under actual working conditions. For example, in the present investigation, direct excitation between the table and the overarm, excluding the arbor, would have resulted in unrealistic frequency values because the effect of the arbor and its bearings would have been excluded.

vibration measurement

Although velocity measurements are useful for estimating the vibration energy and acceleration measurements help in estimating noise levels, in the present investigation, the effect of vibrations on the dimensional inaccuracies of the workpiece was of particular interest. It was therefore decided to concentrate all efforts on the measurement of displacements.

(a) natural frequencies

The pick-up was rigidly clamped to one end of the table in one of the three measuring directions, i.e.,

(a) vertical;
(b) horizontal longitudinal;
(c) horizontal transverse.

The directional sensitivity due to the polarity of the pick-up was always taken into consideration.

(b) natural modes

For determining the natural modes, a movable pick-up was pressed firmly to the machine by hand at the probing positions which had been previously marked on the machine frame comprising the table, arbor, overarm, column, and base whenever possible.

The direction of the probing pick-up was ensured by special attachments made to fit the machine slides at the probing points, Figs. 3(a) and 3(b). Another device was prepared for attaching the pick-up to the arbor in the horizontal and vertical directions, Fig. 3(c).

In order to identify the relative phase of the different members of the machine with respect to each other, a reference pick-up was clamped to the table which measured in the direction of the mode investigated in each case.

dynamic characteristics of the machine

(a) natural frequencies

Some resonance curves obtained from the excitation tests are shown in Figs. 4(a), 4(b) and 4(c).

In the nine configurations which were investigated, the machine was found to have several natural frequencies in the directions of the three arbitrary chosen co-ordinates. These values were distributed in a wide range from 15 c.p.s. up to 150 c.p.s.

Most of the peaks of each resonance curve were not widely spaced or exactly separated. The shape of the curve at any natural frequency did not resemble the usual one of a single degree of freedom system and crinkles appeared on its sides, due to the effect of other modes which were included in the general system and contributed to the total response.

No external force was applied in the transverse direction. Vibrations were, however, found to be excited in this direction as well. The inter-effect between different modes could not, therefore, be overlooked, and it would appear that the treatment of the machine in the vicinity of one of its natural frequencies as a single degree of freedom system would not represent the actual conditions. The machine should be considered as a multi-degree of freedom system, because of the effects caused by coupling of its various members and their different values of rigidity.

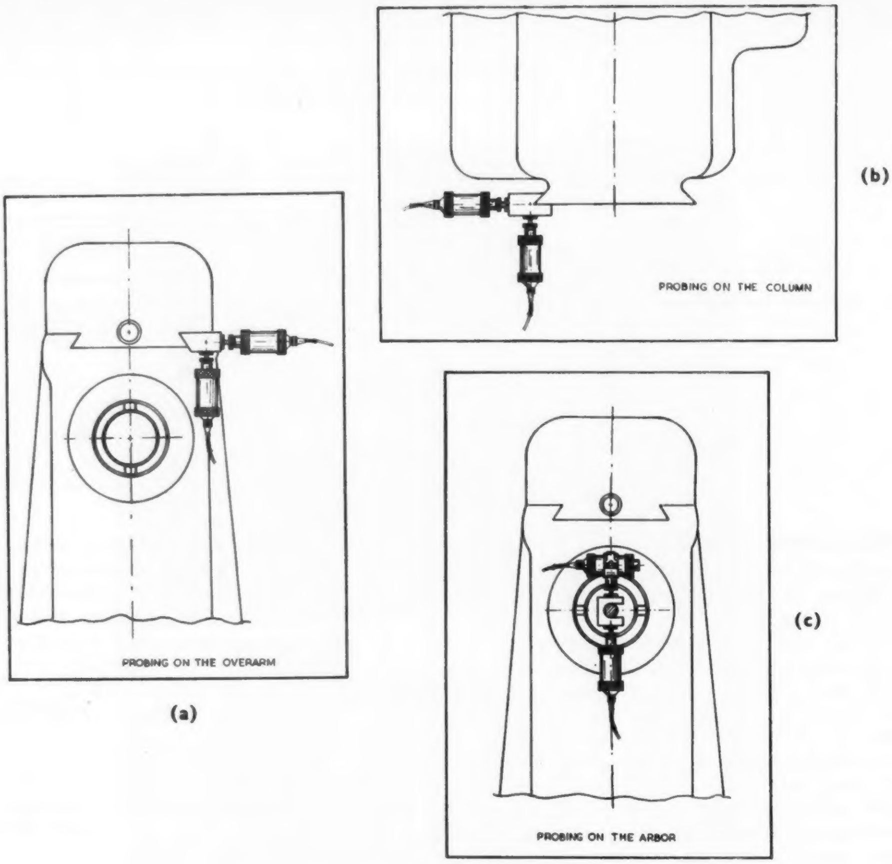

PROBING ON THE OVERARM
(a)
PROBING ON THE COLUMN
(b)
PROBING ON THE ARBOR
(c)

Fig. 3.

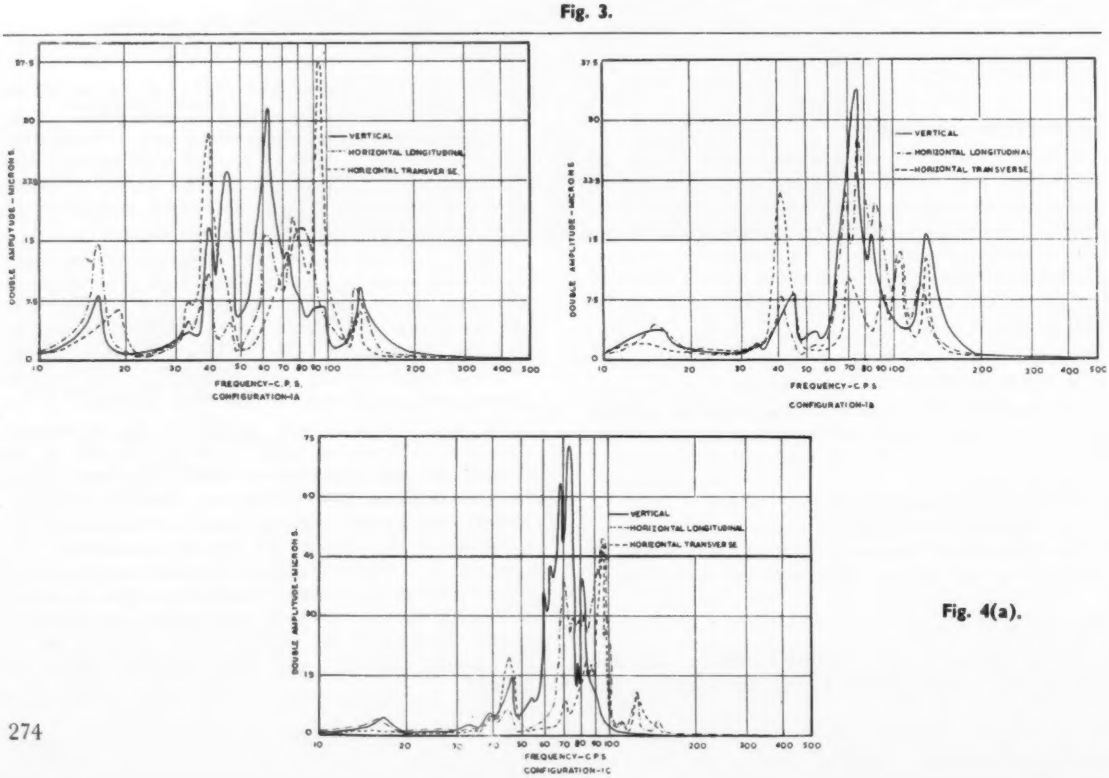

VERTICAL
HORIZONTAL LONGITUDINAL
HORIZONTAL TRANSVERSE
DOUBLE AMPLITUDE – MICRONS
FREQUENCY – C.P.S.
CONFIGURATION–1A
CONFIGURATION–1B
CONFIGURATION–1C

Fig. 4(a).

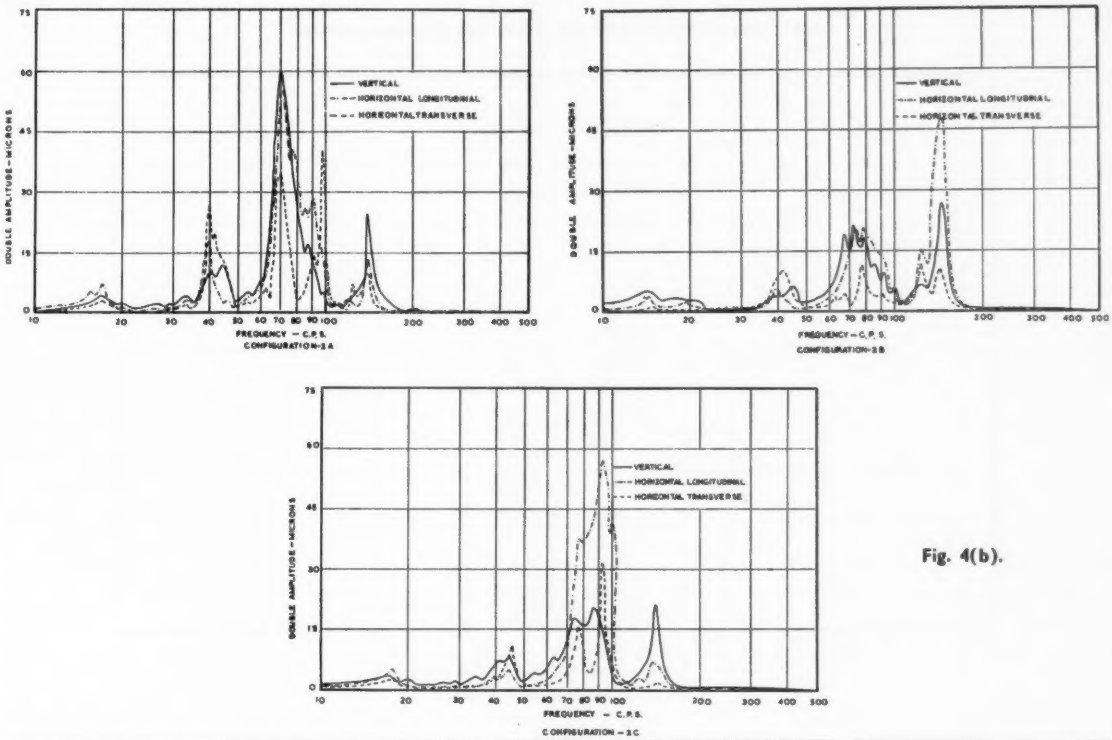

VERTICAL
HORIZONTAL LONGITUDINAL
HORIZONTAL TRANSVERSE
DOUBLE AMPLITUDE-MICRONS
FREQUENCY — C.P.S.
CONFIGURATION-2A
CONFIGURATION-2B
CONFIGURATION-2C

Fig. 4(b).

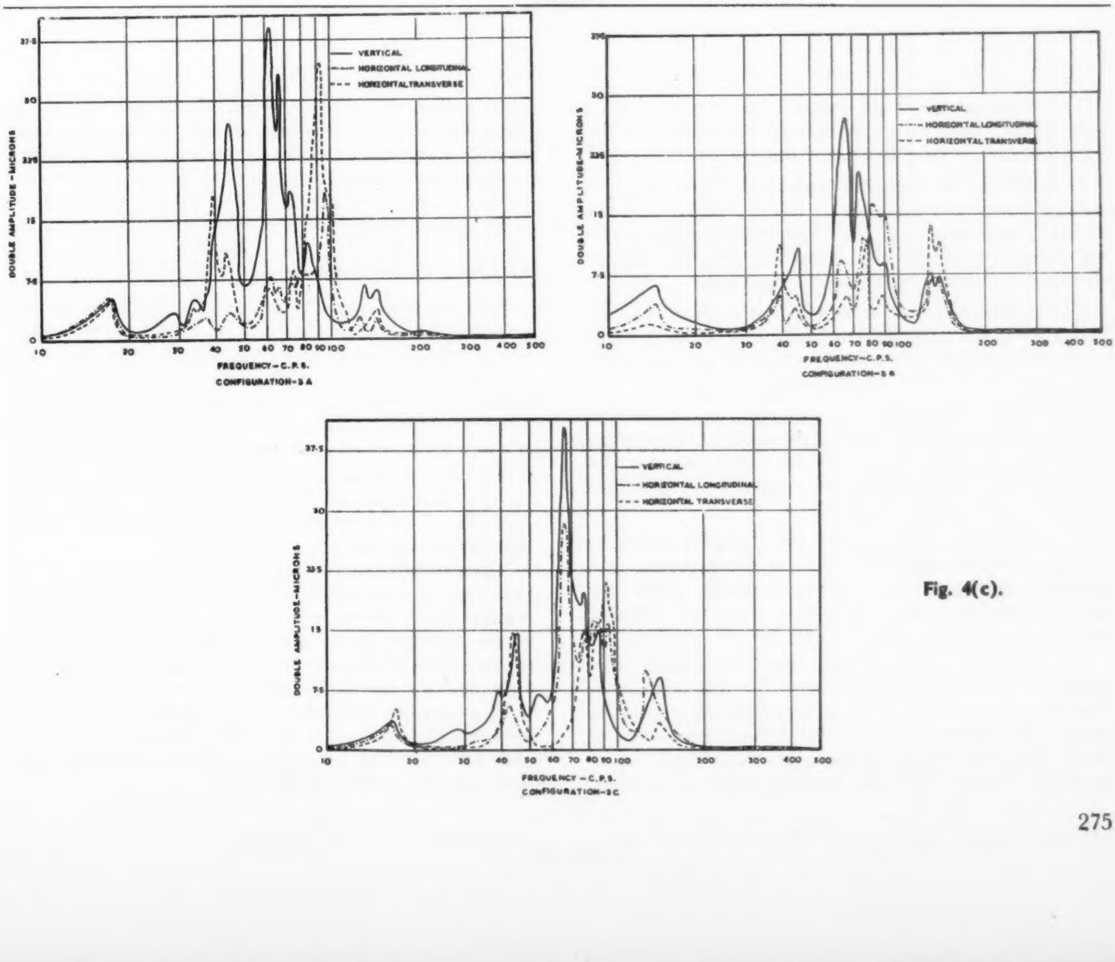

VERTICAL
HORIZONTAL LONGITUDINAL
HORIZONTAL TRANSVERSE
DOUBLE AMPLITUDE-MICRONS
FREQUENCY — C.P.S.
CONFIGURATION-3A
CONFIGURATION-3B
CONFIGURATION-3C

Fig. 4(c).

NATURAL FREQUENCIES OF SELECTED SERIOUS MODES

	A			B			C		
	V	H_x	H_y	V	H_x	H_y	V	H_x	H_y
	—	—	39	—	—	—	—	—	—
	45	—	—	—	—	42	—	—	—
1	62	62	—	—	—	—	—	—	—
	—	—	76	75	76	—	72	70	—
	—	—	94	—	—	—	82	95	95
	70	—	70	72	74	—	—	—	—
2	—	—	—	—	—	—	85	—	—
	—	—	—	—	—	—	—	92	92
	—	—	—	145	145	145	—	—	—
	45	—	—	—	—	—	—	—	—
	62	—	—	66	—	—	66	—	—
3	—	—	—	73	—	—	—	—	—
	84	—	—	—	82	—	—	—	—
	—	—	92	—	—	—	—	—	—

V — *Vertical Modes*
H_x — *Longitudinal Horizontal Modes*
H_y — *Transverse Horizontal Modes*

Fig. 5.

The distribution of the natural frequencies over a wide range could cause resonance excitation by the fundamental cutting force and its harmonics.

It is difficult to design a perfect machine which is entirely free from resonance effects, unless all the natural frequencies are shifted either below the working range or above the frequency of the highest effective harmonic in the working range.

The difficulties encountered in the first case lie in the fact that one has to bring down the natural frequencies of members such as the arbor, the overarm, etc., to a value below 10 c.p.s.

The other alternative is, perhaps, easier as the practical difficulties in shifting the natural frequencies above the working range can be overcome, e.g., by making use of light weight construction (see Koenigsberger [1] and [2] and Opitz[3]).

At each natural frequency, the damping capacity varies, and at different natural frequencies and different configurations of the machine parts the dynamic stiffness may vary even over the working length of a certain job.

In practice, it is difficult for a machine tool designer to design all members in such a manner that their natural frequencies lie outside the working ranges. Moreover, changing the natural frequency of some members which initiate resonance may well move the danger from one working range to another.

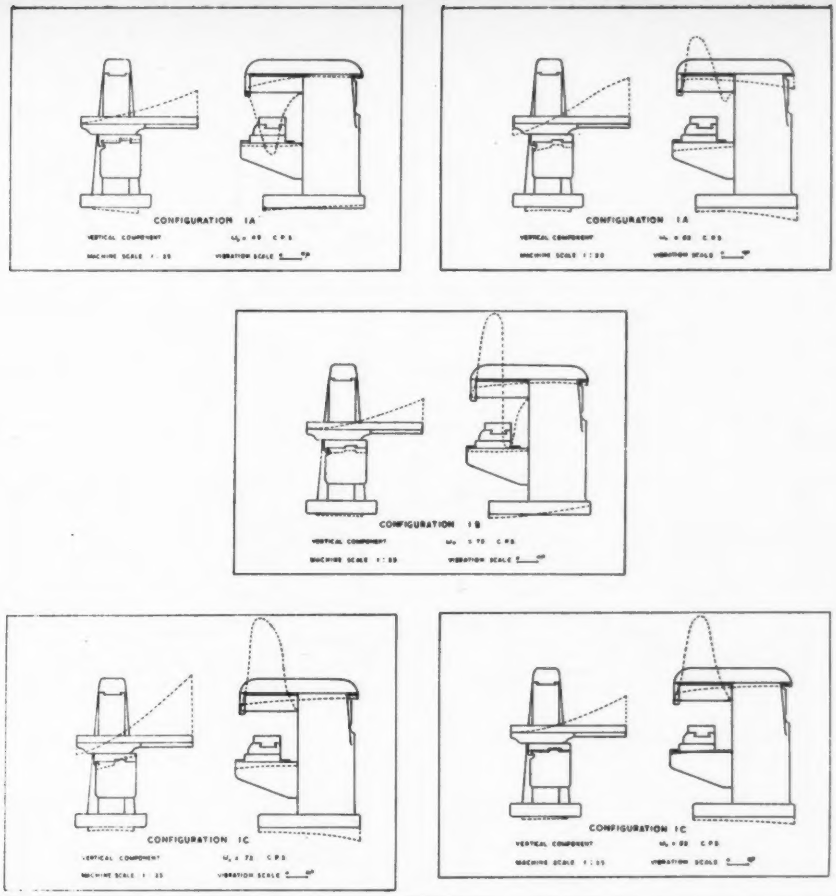
In order to obtain better dynamic behaviour, damping would therefore appear to be the most reliable means of suppressing the serious modes which in practice may be difficult to move outside the working range. A high damping value will also assist in obtaining uniformity of dimensional accuracy.

(b) the natural modes

The natural frequencies of the selected serious modes are shown in Fig. 5. The elastic curves representing the deformations of the machine are presented in Figs. 6 to 8. The vertical modes are represented in Figs. 6(a) to 6(c). The horizontal longitudinal modes are represented in Figs. 7(a) and 7(b). The horizontal transverse modes are represented in Figs. 8(a) and 8(b).

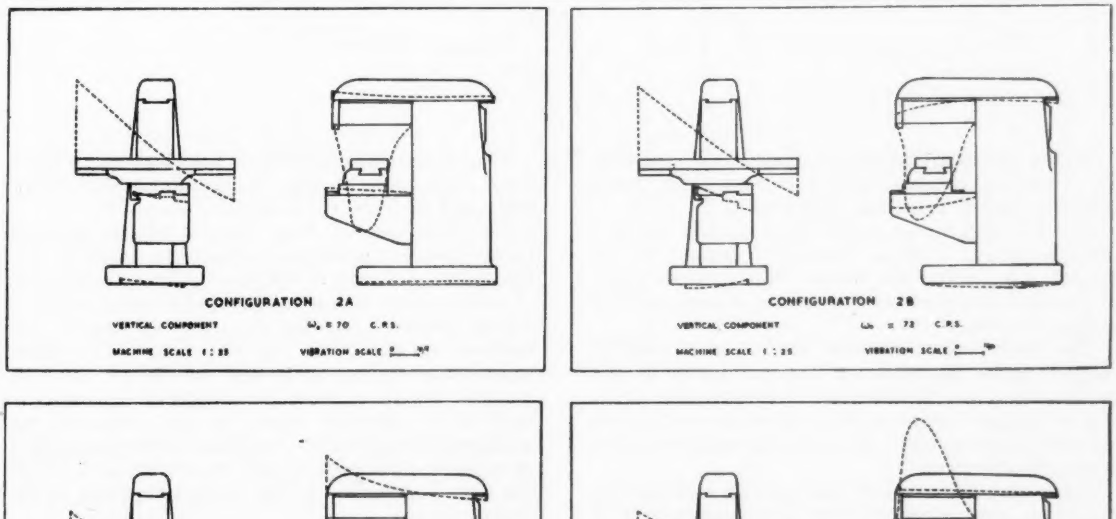
The deformations of the members of the machine in the direction of the investigated modes were represented at their maximum excursions by dotted lines in the figures.

The deformation of the table is far greater at the ends than it is below the arbor where, during cutting, contact takes place between the workpiece and the cutter. In some of the modes nodal points were found on the table or the arbor. It is doubtful whether the existence of these nodal points can be used in practice with a view to minimising the relative displacement between the arbor and the table. These nodal points exist only at some frequencies and they change position with the table configuration.



CONFIGURATION 1A
CONFIGURATION 1A
CONFIGURATION 1B
CONFIGURATION 1C
CONFIGURATION 1C

Fig. 6(a).



CONFIGURATION 2A
VERTICAL COMPONENT
C.P.S.
MACHINE SCALE 1 : 25
VIBRATION SCALE
CONFIGURATION 2B
VERTICAL COMPONENT
C.P.S.
MACHINE SCALE 1 : 25
VIBRATION SCALE
CONFIGURATION 2B
VERTICAL COMPONENT
C.P.S.
MACHINE SCALE 1 : 25
VIBRATION SCALE
CONFIGURATION 2C
VERTICAL COMPONENT
C.P.S.
MACHINE SCALE 1 : 25
VIBRATION SCALE

Fig. 6(b).

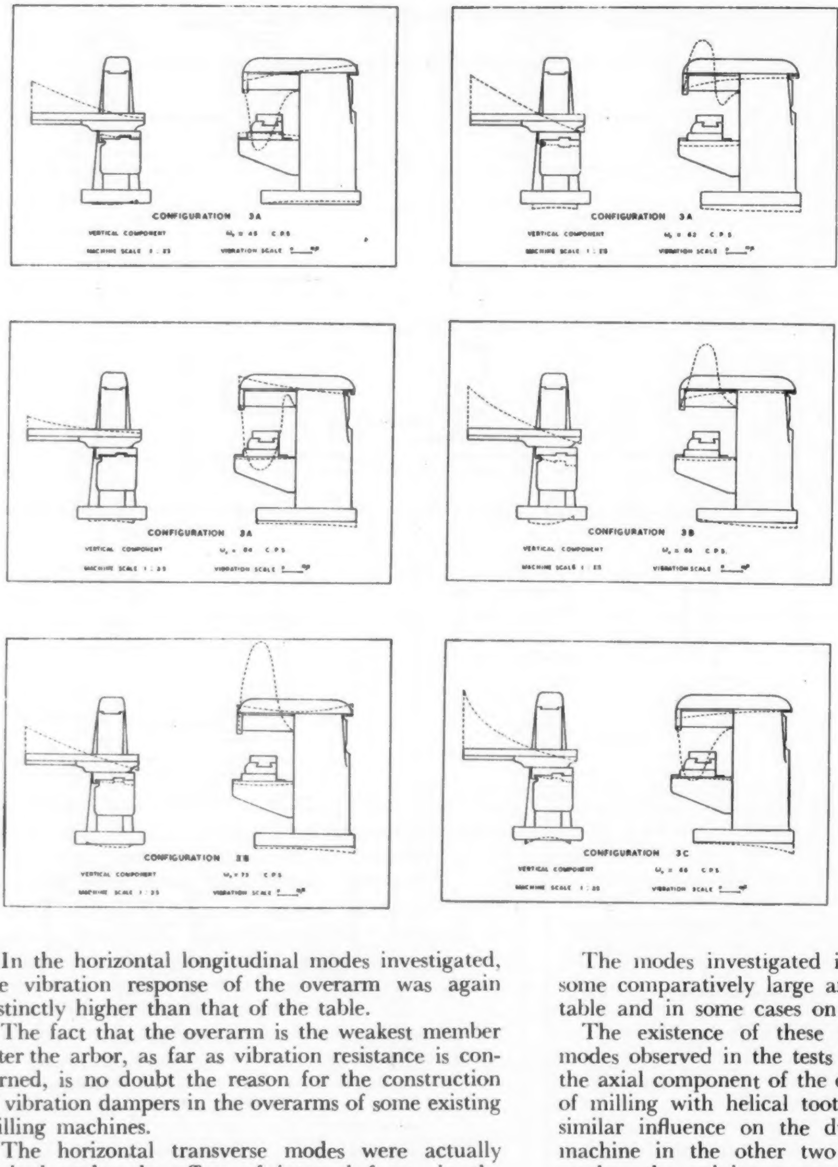


Fig. 6(c).

In the horizontal longitudinal modes investigated, the vibration response of the overarm was again distinctly higher than that of the table.

The fact that the overarm is the weakest member after the arbor, as far as vibration resistance is concerned, is no doubt the reason for the construction of vibration dampers in the overarms of some existing milling machines.

The horizontal transverse modes were actually excited under the effect of internal forces in the machine because the direction of external excitation was in a plane normal to the axis of the cutter, and no external forces were acting on the machine in the transverse direction.

While the excitation process was limited to two directions, the vibrations were also measured in a third direction, in order to throw some light on the effect of milling operations with straight teeth cutters on vibrations in the transverse directions. It was found that even with a straight tooth cutter, an oscillatory relative motion in the transverse direction existed between the cutting edge and the workpiece. This cannot be neglected as it may have a detrimental effect on the tool life.

The modes investigated in this direction showed some comparatively large amplitudes mostly on the table and in some cases on the column.

The existence of these mutual effects between modes observed in the tests appears to indicate that the axial component of the cutting force (in the case of milling with helical tooth cutter) would exert a similar influence on the dynamic response of the machine in the other two directions. This would weaken the opinion expressed by Opitz [3] that the machine should be tested only under the effect of a load in the direction normal to the surface of the machined workpiece. It would also justify the method of excitation followed in this investigation in which the load was applied in the general direction of the cutting force.

behaviour of the machine during running

(a) probable vibrations due to the transmission

The transmission of the machine spindle shown in Fig. 9(a) was examined for interference between the values of the natural frequencies and the range of speeds of the spindle transmission shafts.

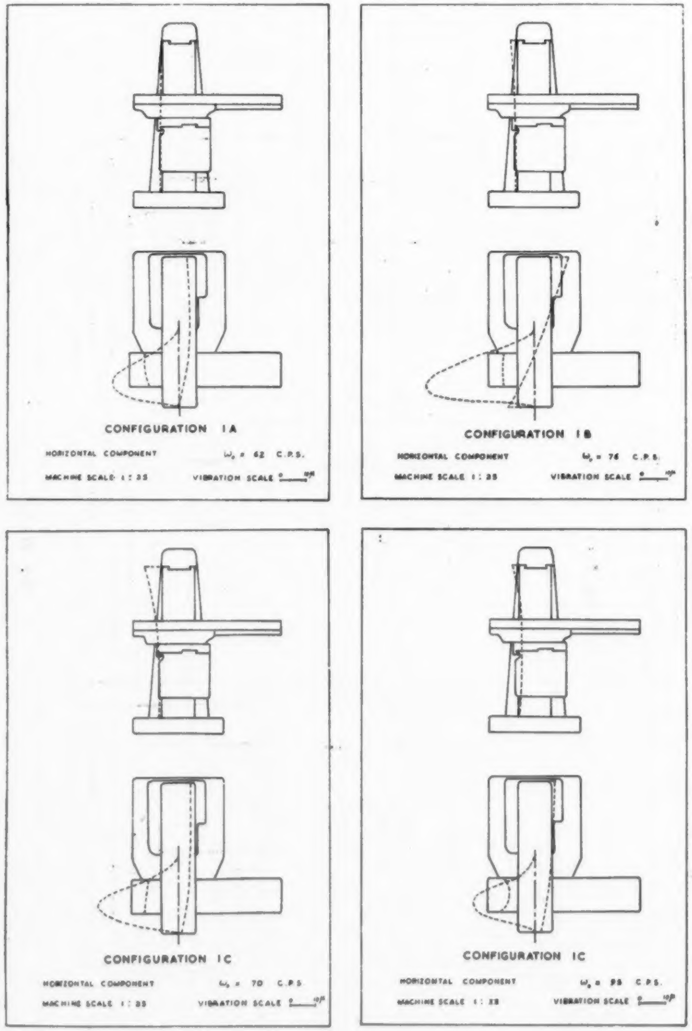

CONFIGURATION 1A
HORIZONTAL COMPONENT
ω_1 = 62 C.P.S.
MACHINE SCALE
VIBRATION SCALE
CONFIGURATION 1B
HORIZONTAL COMPONENT
ω_1 = 76 C.P.S.
MACHINE SCALE
VIBRATION SCALE
CONFIGURATION 1C
HORIZONTAL COMPONENT
ω_1 = 70 C.P.S.
MACHINE SCALE
VIBRATION SCALE
CONFIGURATION 1C
HORIZONTAL COMPONENT
MACHINE SCALE
VIBRATION SCALE

Fig. 7(a).

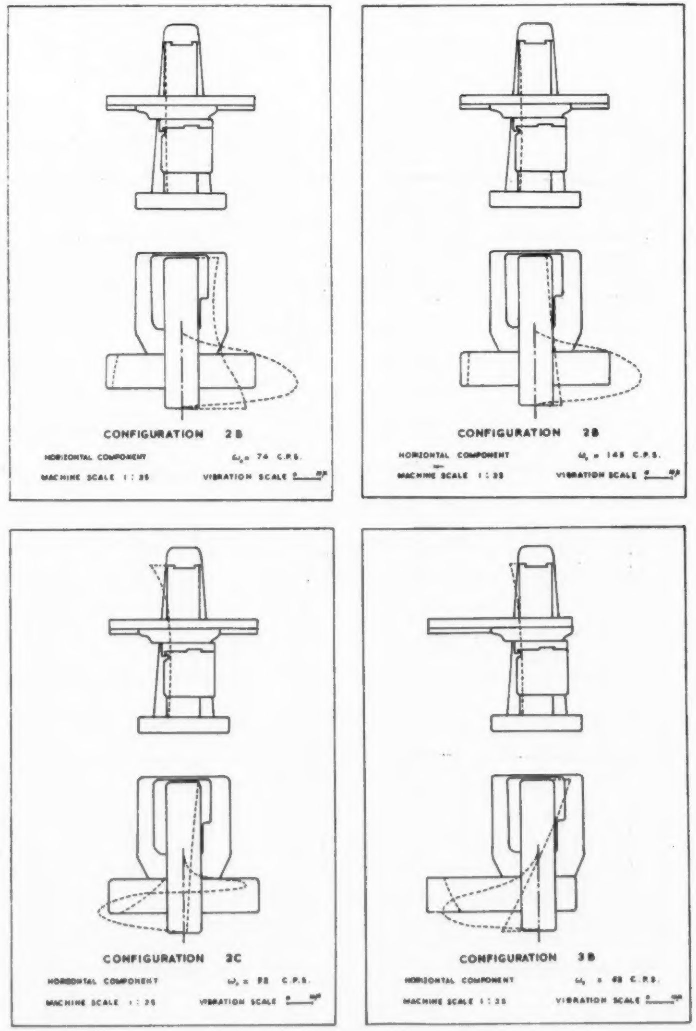

CONFIGURATION 2B
HORIZONTAL COMPONENT
ω_1 = 74 C.P.S.
MACHINE SCALE
VIBRATION SCALE
CONFIGURATION 2B
HORIZONTAL COMPONENT
ω_1 = 145 C.P.S.
MACHINE SCALE
VIBRATION SCALE
CONFIGURATION 2C
HORIZONTAL COMPONENT
MACHINE SCALE
VIBRATION SCALE
CONFIGURATION 3B
HORIZONTAL COMPONENT
MACHINE SCALE
VIBRATION SCALE

Fig. 7(b).

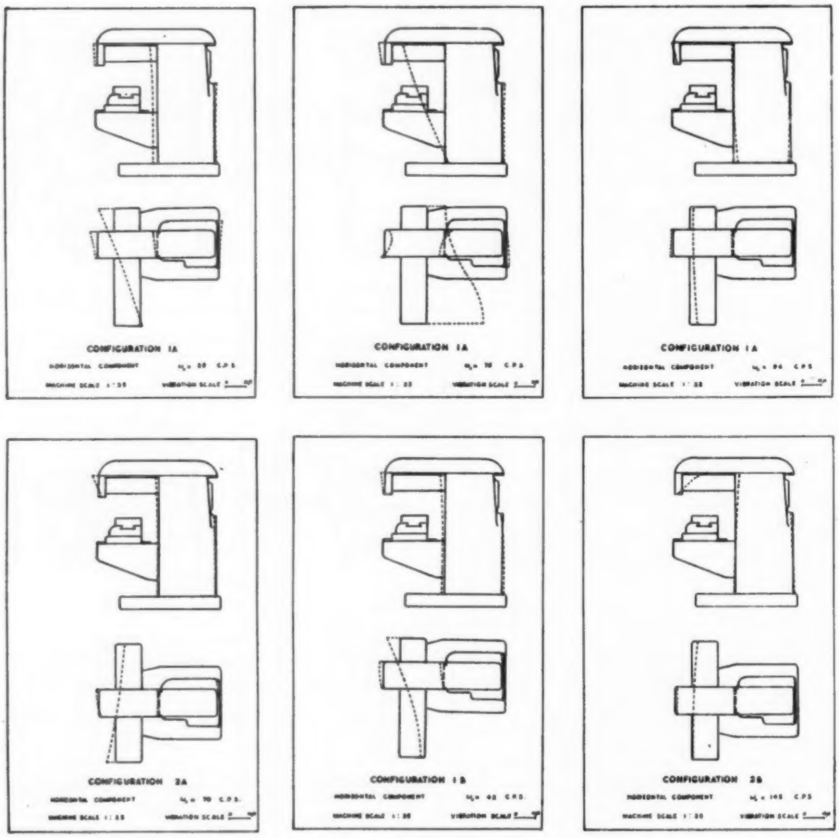

CONFIGURATION 1A
CONFIGURATION 1A
CONFIGURATION 1A
CONFIGURATION 2A
CONFIGURATION 1B
CONFIGURATION 2B

Fig. 8(a).

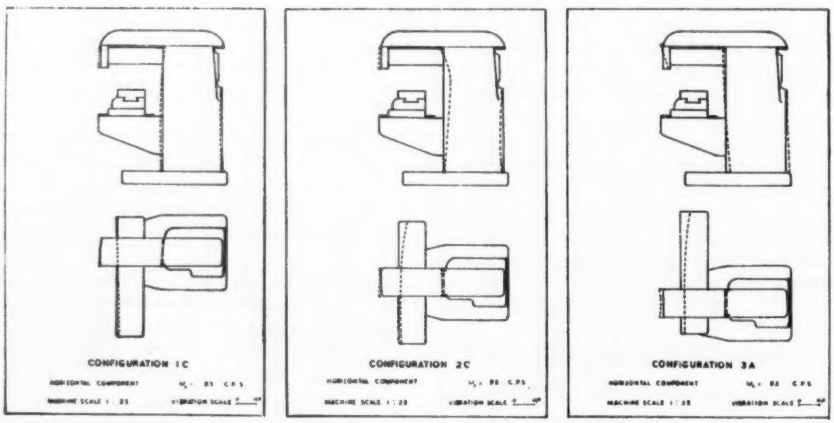
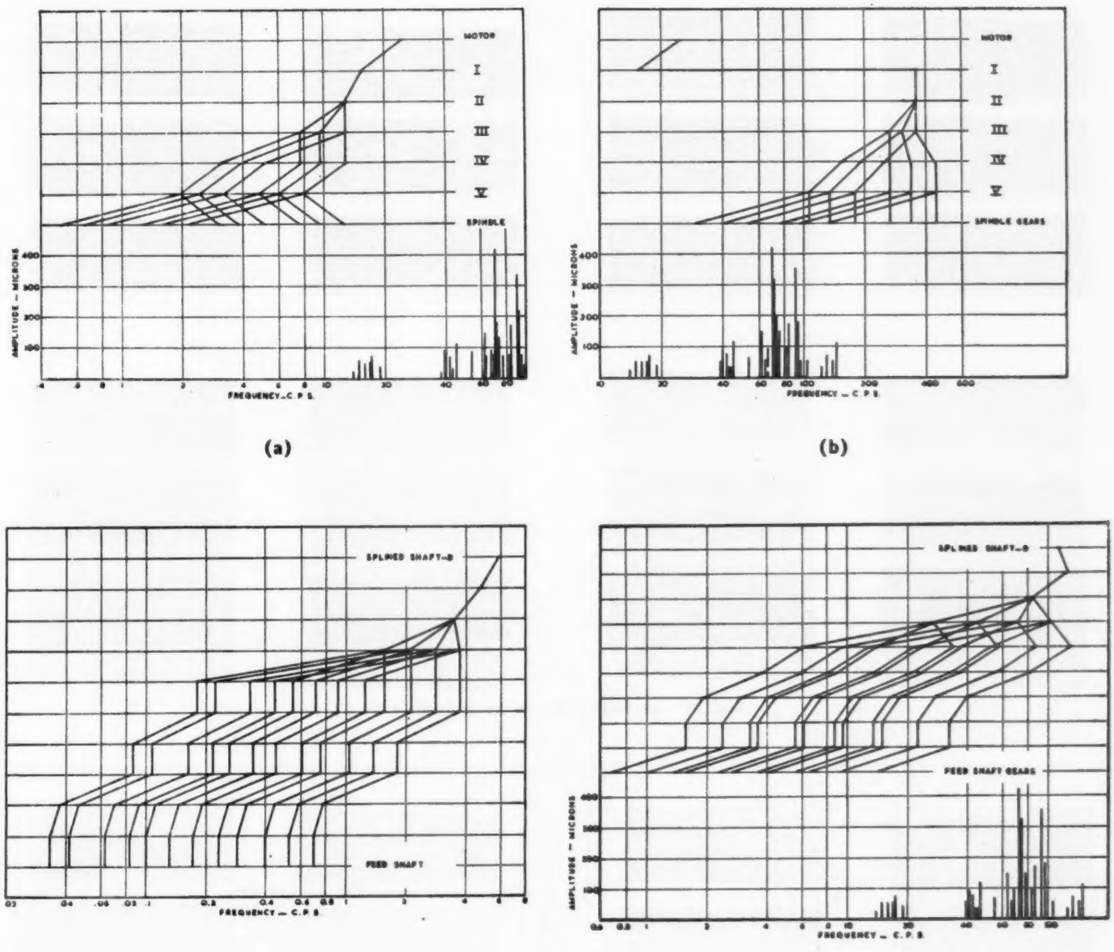

CONFIGURATION 1C
CONFIGURATION 2C
CONFIGURATION 3A

Fig. 8(b).



(a) (b) (c) (d)

Fig. 9.

The speed of shaft (I) in the spindle transmission is 15.7 c.p.s. which is in the vicinity of a range of natural frequencies closely scattered at different configurations between 15 and 17.15 c.p.s. This shaft carries the driving pulley which transmits the power from the motor to the machine. A centrifugal force at the pulley would be able to excite the aforementioned natural frequency unless the pulley was balanced to a high degree of accuracy.

The tooth contacts of the spindle transmission gears (Fig. 9(b)) shows interference with the natural frequencies at spindle speeds of 38 r.p.m., 74 r.p.m., 93 r.p.m., 125 r.p.m., 186 r.p.m. and 232 r.p.m.

The speeds of the feed shafts and the contact frequencies of their gears shown in Figs. 9(c) and 9(d) gave only slight interference near the high feed rates.

(b) actual vibrations due to the transmission

Records of the vibrations during idle running of the transmission are shown in Fig. 10. The graphs in Fig. 11 show the vibration amplitudes obtained from the records.

A vibration frequency of 15.7 c.p.s. was found in all idle running tests. This frequency is equal to that of one of the probable excitation sources in the transmission system, i.e., the main input shaft carrying the driving pulley.

The amplitude of this wave increased when the gear box was coupled with the pulley. Only slight variations in the amplitudes were found at different spindle speeds or feed rates.

No other considerable frequencies appeared in addition to the previously mentioned one under all investigated conditions.

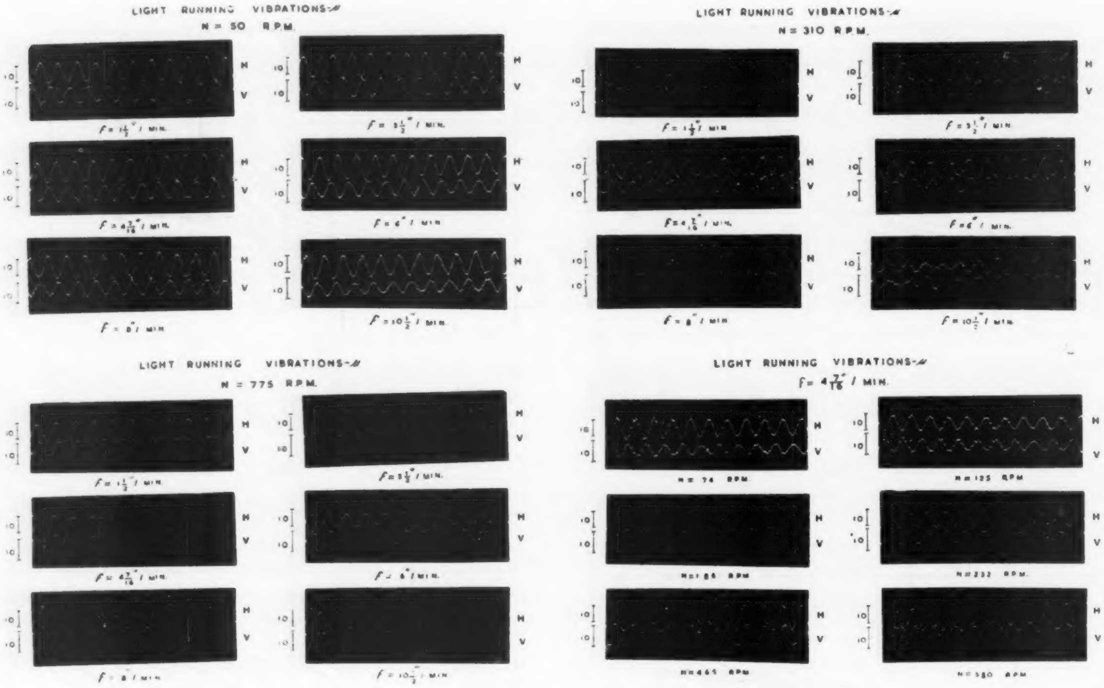


Fig. 10 (All amplitudes to be multiplied by 2).

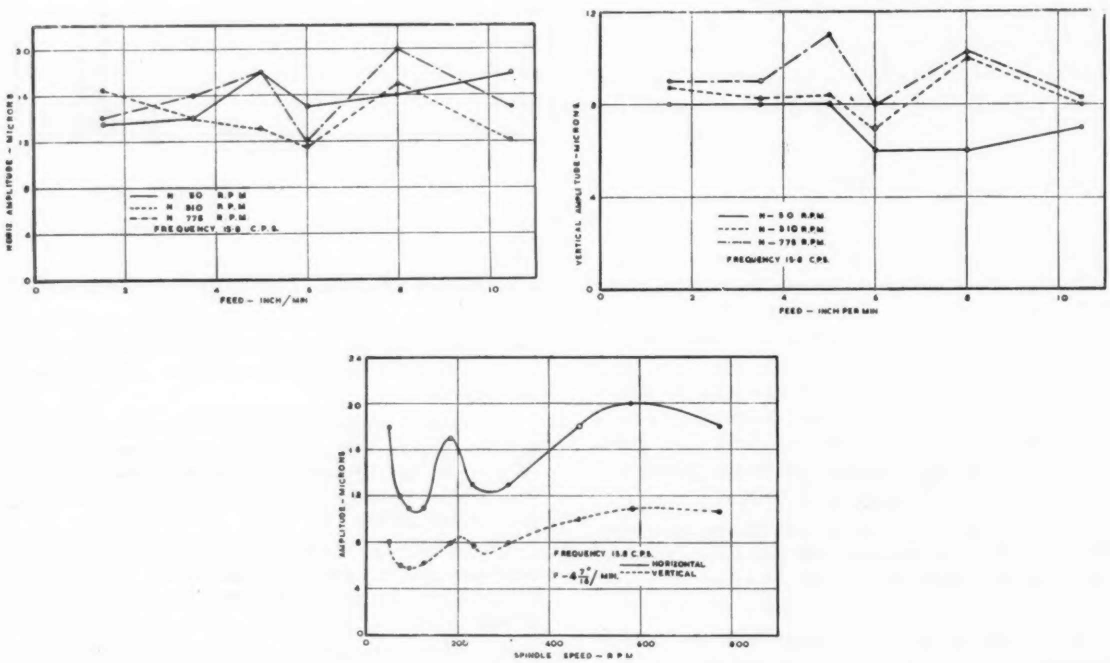


Fig. 11.

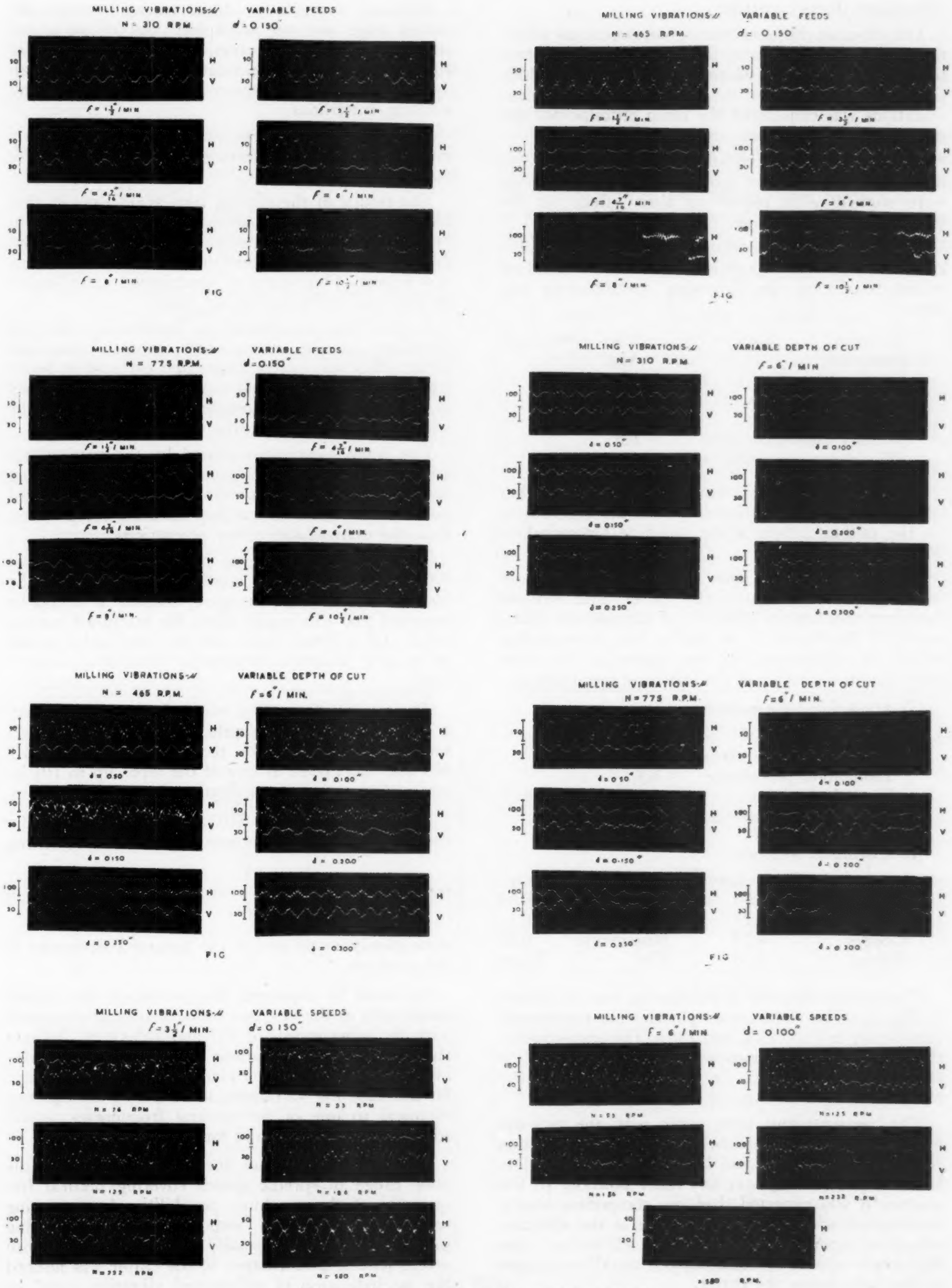


Fig. 12. (All amplitudes to be multiplied by 2.)

vibrations during cutting

The effect of different cutting conditions on vibrations induced during the milling process has often been attributed to the existence of self-excited vibrations, and the degree of the resistance to self-excited vibrations was considered the main criterion for the stability of the machine.

As the effect of forced vibrations is, however, also important, both forced and self-excited vibrations were studied with regard to their effect on the vibration of the machine.

In order to obtain conditions which would become comparable to those occurring in practice, a standard milling cutter of the following specifications was used :

Material	High speed steel
Diameter	4 in.
Number of teeth	14
Width of cutter	$\frac{1}{8}$ in.
Rake Angle	12°
Primary clearance angle ...	10°
Side clearance angle ...	1°

Although the cutter was running true within 0.0005 in. on an inspection mandrel, the eccentricity on the milling arbor of the machine amounted to 0.0015 - 0.002 in.

In order to cover a wide range of speeds without reducing the tool life of the cutter, and without therefore creating the difficulty of varying the eccentricity of the cutter or its angles due to regrinding effects, an aluminium alloy was chosen for the workpiece material which had the following specifications :

(a) *Mechanical Properties*

Brinell hardness	= 136
Ultimate tensile strength	= 28.4 tons/in.^{2}
Elongation percentage	= 6%
Young's modulus	= 10.6×10^6 lb./in.^{2}
Ultimate shear strength	= 17.4 tons/in.^{2}

(b) *Chemical Analysis*

	Percentage		Percentage
Aluminium	94.00	Manganese	0.69
Iron	0.27	Zinc	0.1
Copper	4.27	Magnesium	0.22
Silicon	0.45	Tin	Trace

The records obtained in the cutting tests are shown in Fig. 12. The vibration amplitudes are represented graphically in Figs. 13(a) and 13(b). The amplitudes of the vibration components with frequencies equal to those of the cutter teeth, i.e., due to the cutting force only, are shown in Fig. 13(b).

The measurements were taken with the pick-ups at one end of the table where, from the deformation results, the vibrations had been previously found to be usually higher than at any other position. In this manner it was expected that any component should be detected which might contribute to the resultant vibration, especially to a probable self-excited type that might appear at the arbor but could be damped at the table below the cutter.

Although the relative displacement between the cutting edge and the workpiece was of particular interest in this investigation, it was still practically difficult to measure the relative vibrations between the arbor and the workpiece of the machine during working conditions.

Absolute measurements were, therefore, the only available means for assessing the vibrations in this case.

The results of the cutting tests again showed that the machine under consideration was always subjected to a forced vibration which was due to an unfavourable speed of one member of the transmission system. This vibration contributed considerably to the total vibration in all cases.

A vibration component in agreement with the frequency of the cutter teeth contacts was also found. This was mostly modulated on another lower frequency wave which corresponded to the frequency of the arbor, due apparently to the effect of the unavoidable cutter eccentricity.

The wave component caused by the cutting frequency did not attain a constant amplitude during one revolution of the spindle, especially at low feed rates where the maximum chip thickness could be less than the unavoidable cutter eccentricity.

The maximum peak to peak value during one cycle of any wave was considered to represent the double amplitude of the wave, because it would be expected that this would affect the machined surface most, and a mean value for the amplitudes would be of little practical importance from this point of view.

The results of the first two series of cutting tests, at different feeds and depths of cut showed no self-excited vibrations at the three spindle speeds 310, 465 and 755 r.p.m., at any of the feeds up to $10\frac{1}{2}$ in. per minute or any of the depths of cut up to 0.300 in.

A spindle speed of 310 r.p.m. was intentionally chosen for these tests because it provided an exciting

frequency of $310 \times \frac{14}{60} = 72$ c.p.s. which was in close proximity to one of the natural frequencies of the machine.

As could be expected, this produced the highest amplitudes in the first two series of tests as compared with the other speeds of 465 and 755 r.p.m., because the amplitudes of vibrations were considerably magnified when cutting took place in a resonance range. In this case the vibrations, although of a frequency identical to one of the natural frequencies, would still have to be considered forced vibrations.

In the third series of the cutting tests with the wide range of spindle speeds covering natural frequencies of the machine, possibilities for initiating self-excited vibrations were considerable. During some of these tests, unusually loud noise coupled with severe jerking performance of the cutter was noticed but no indication of self-excited vibration could be

found on the oscilloscope records. The vibration component with a frequency identical to a natural frequency of the machine was only found when the fundamental frequency of the cutting edge or one of its harmonics coincided with that of the natural frequency.

This kind of vibration is a resonance vibration and not, by definition 4, a self-excited vibration. In none of the cutting tests investigated was the existence of self-excited vibrations detected.

It thus appears that, differing from the case of the lathe or drilling machine, self-excited vibration is not a factor deciding the stability of the milling machine.

When the amplitudes of both the total vibration or its components caused by the cutting force were plotted against the corresponding cutting conditions, no definite tendency to follow a special pattern could be detected. This may be due to the variations in the waveform of the cutting force which would result in harmonics of different frequencies even for the same fundamental frequency. If the frequencies of these harmonics lie in different dynamic regions of the multi-degree of freedom machine, they will produce different total vibration response.

surface quality

A perfectly flat surface cannot be expected even when a milling operation is carried out with an ideal machine, i.e., a machine free from vibrations. The trochoidal path of the milling cutter forms waves of a length equal to the feed per tooth (f_t) and a height equal to

$$h = \frac{f_t^2}{8(D/2 + f_t\, T/\pi)} \text{ in.}$$

where D = diameter of cutter – in.
and T = number of teeth
a good approximation in the present conditions

$$\text{is } h = \frac{f_t^2}{4D}.$$

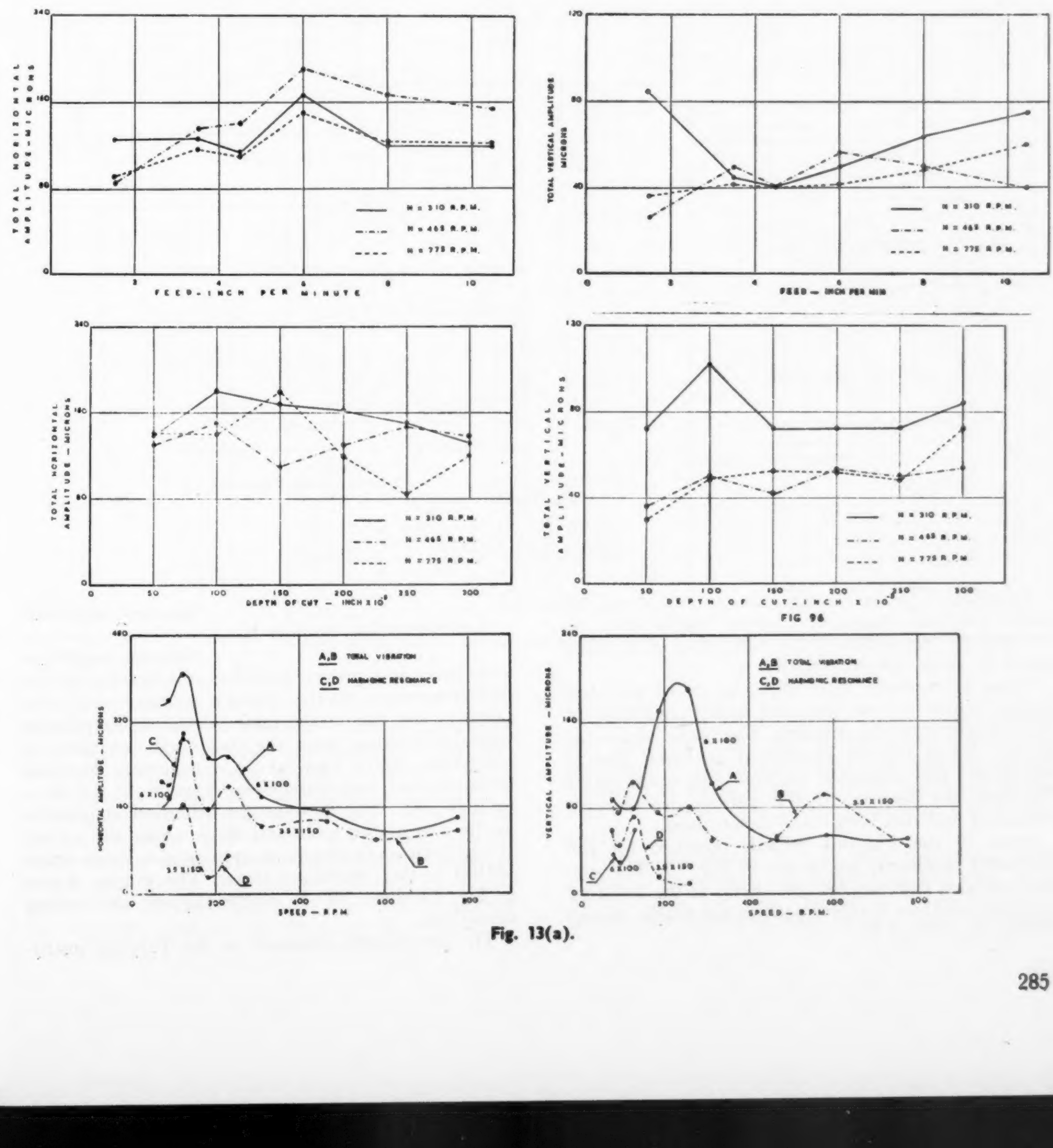


Fig. 13(a).

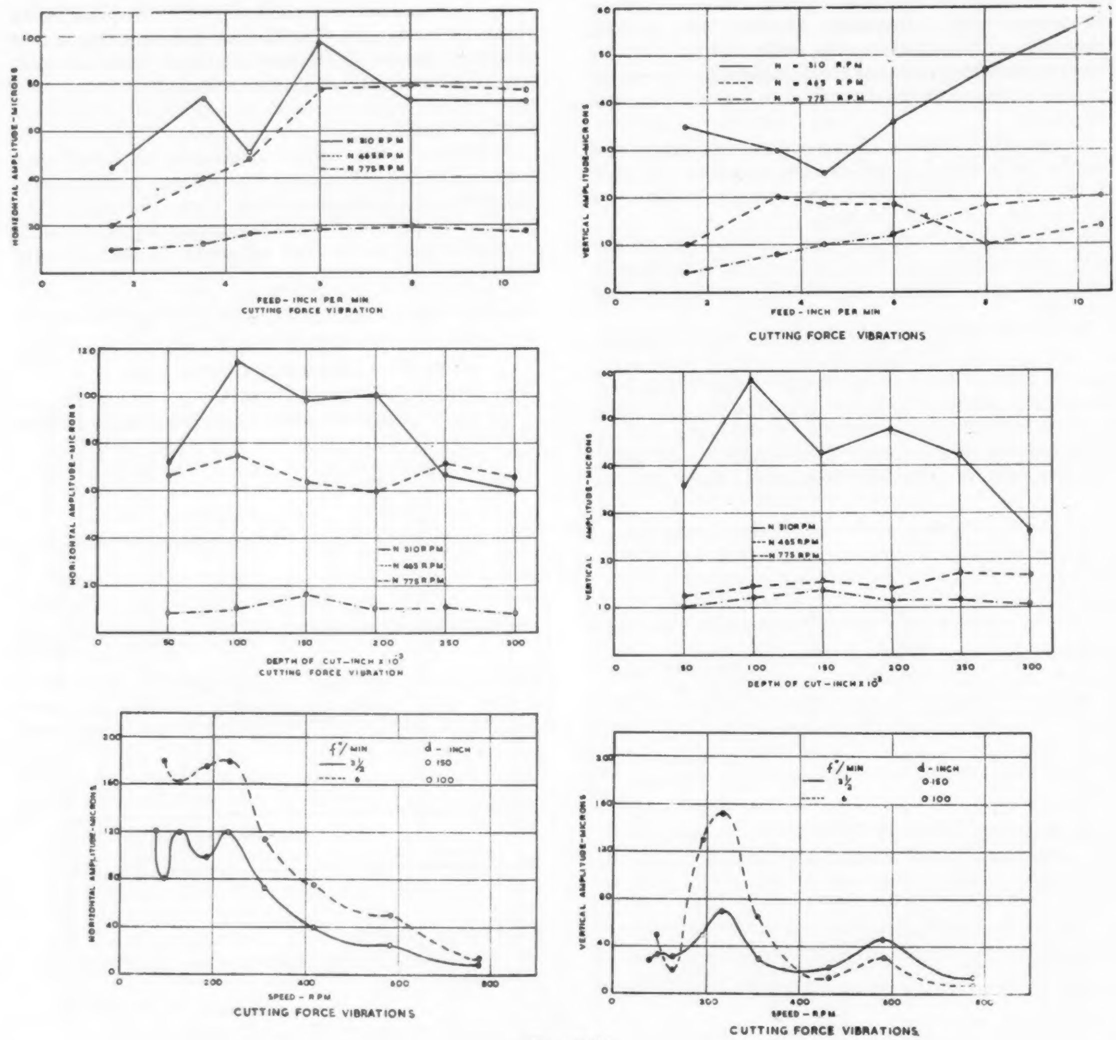


Fig. 13(b).

In addition to these waves, the eccentricity of the cutter produces waves of a wave length equal to the feed per revolution of the cutter and of a height equal to twice the eccentricity.

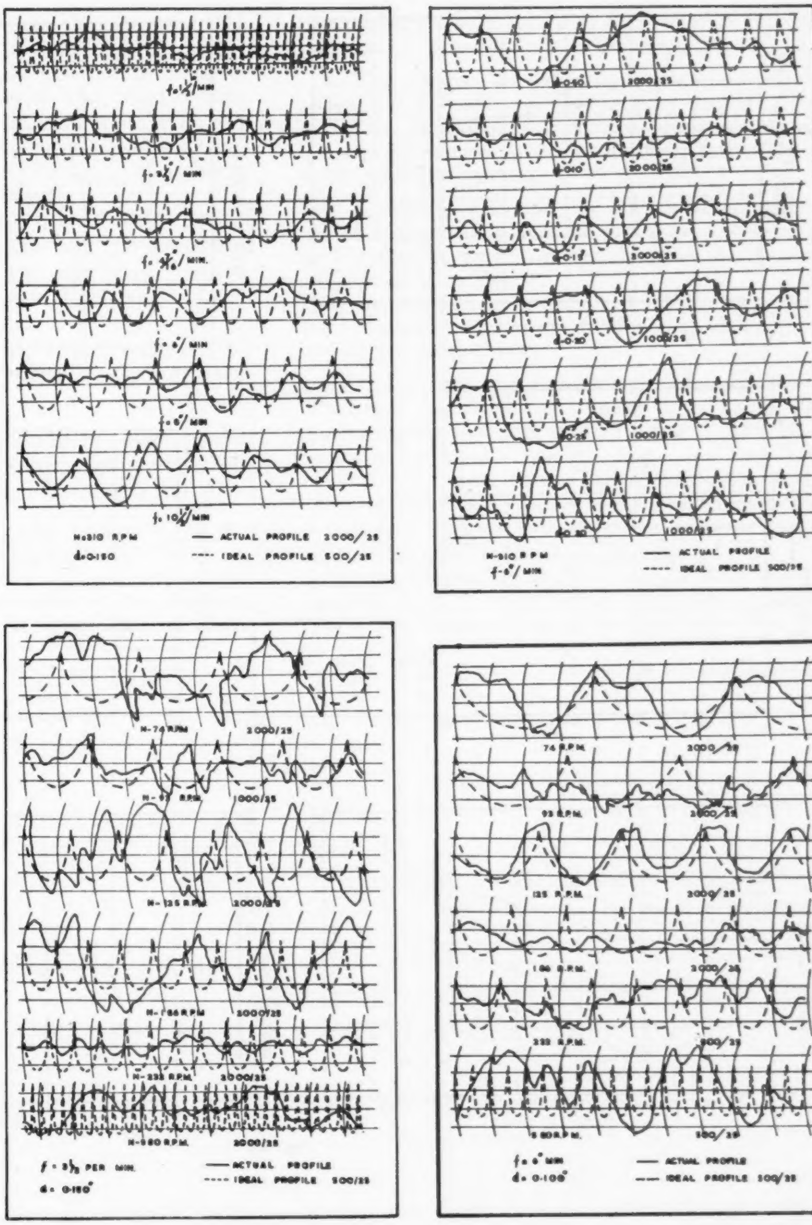
These waves form what might be called the ideal surface which can be obtained under conditions of infinite stiffness of the machine. The major additional surface waves will be considered as being due to vibrations. The machined surfaces were tested with a Talysurf, the lengths of the various waves were measured and their frequency determined.

Some of the Talysurf records obtained for the machined specimens are shown in Fig. 14. The surface waviness due to vibration effects at the different cutting conditions is represented in the graphs shown in Figs. 15, 16 and 17.

A dimensionless number $K = \dfrac{\text{waviness amplitude}}{\text{vibration amplitude}}$ was chosen to represent the effect of vibrations on the surface waviness. As the vibration measurements were taken at the end of the table where the amplitudes were higher than near the machined workpiece, a correction factor had to be introduced. Previous measurements had shown (see Figs. 6, 7 and 8) a ratio of (60 : 200) between the vibration amplitudes at the end of the table and those under the cutter. It was decided to choose an approximate mean value of 100 as this correction factor. The graphs shown in Fig. 15 show 100 **K** plotted against the cutting conditions.

The pen records obtained on the Talysurf instru-

Fig. 14.



ment for the surfaces produced during the cutting tests did not show specific regular patterns. The profiles obtained were combinations of several waves resulting from different contributory sources.

Measurements of a definite periodic waveform of the surface could not be carried out because even the ideal surface would contain non-uniform waves in length and height due to the eccentricity of the cutter. The average value was therefore considered for the most predominant wave on the surface.

The frequency of the surface waviness did not show any agreement with the natural frequencies of the machine. A dominating effect of the self-excited vibration or chatter could thus not be found on the machined surface under the conditions which were tested.

It was interesting to note that the actual wave length in most cases was larger than the ideal revolution wave, but that the actual wave amplitude was always less than that of the ideal revolution

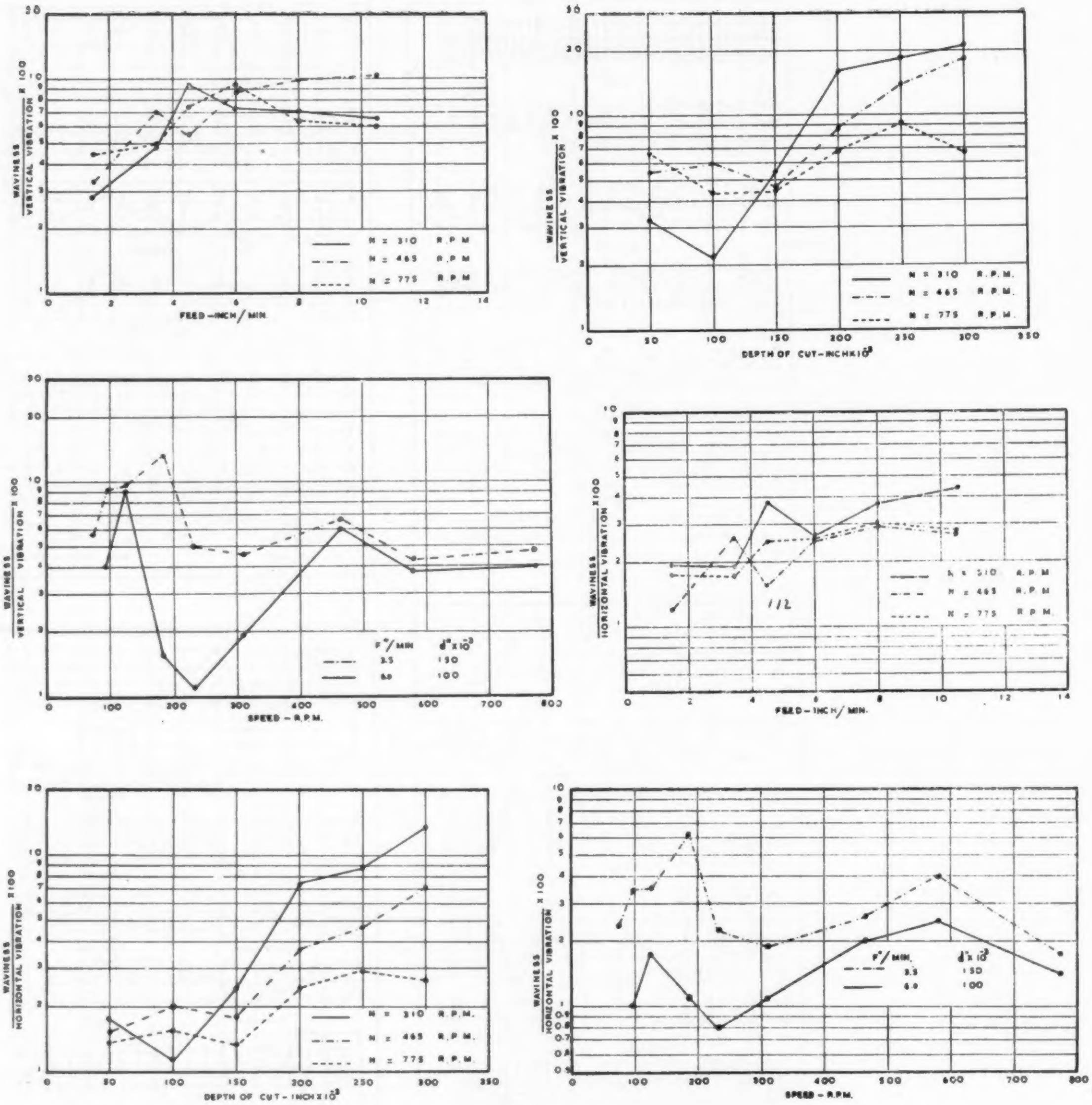


Fig. 15.

wave, even when only one single tooth was cutting.

The milling cutter used had a total eccentricity on the arbor of 1,500 μ in. It would therefore be expected that the ideal milled profile would contain revolution waves of amplitudes equivalent to the cutter eccentricity, i.e., of the order of 1,500 μ in. independent of the cutting conditions. The records obtained by the Talysurf did not show any waviness of more than 600 μ in.

The explanation for the smaller waviness existing on the actual machined profile, as compared with that of the ideal profile, would appear to be the effect of relative displacement between the cutter and the workpieces due to horizontal vibrations. This would help in removing certain portions of the surface peaks and therefore reduce the total waviness on the actual surface.

In the feed range investigated, the waves due to the cutter teeth effects were of minute heights in relation to the heights of the revolution waves. These waves were not visible on the records up to a magnification of 10,000 times.

conclusions

1. The dynamic testing procedure simulating the working conditions of the milling machine emphasised that the machine represents a multi-degree of freedom system with natural frequencies distributed over

a wide range. The machine under consideration had a range of spindle speeds of 29 - 775 r.p.m. As multi-teeth cutters are normally used, care had to be taken to avoid coincidence between the fundamental frequency of cutting or any of its harmonics on the one hand and the natural frequencies of the machine, which varied from 15 c.p.s. - 150 c.p.s. at varying damping capacities, on the other.

It would appear, therefore, that theoretical solutions which separate the modes and use simplified assumptions of a single or two dgeree of freedom system would not cover the actual behaviour of the machine.

The method suggested in 3 for exciting the machine only in a direction normal to the machined surface is not sufficient.

2. The total dynamic rigidity of the machine can be improved by stiffening the two relatively weakest members, i.e., the arbor and the overarm.

3. Interference between the driving system and the natural frequencies of the machine could be a source of permanent serious vibration. The raising of the frequencies of some members such as the overarm, table, etc., e.g., by the use of lightweight construction methods, would appear to be a means of clearing the working range from such interference.

4. The danger of self-excited vibrations would appear to be slight in the milling machine, but resonance vibrations due to the fundamental frequency of cutting or any of its harmonics would have to be carefully watched.

5. A realistic criterion for the dynamic performance of the milling machine would be its resistance to vibrations in general rather than the resistance to self-excited vibrations.

Resonance vibrations occurred during some tests but self-excited vibrations could not be detected in any of the cutting tests.

6. The quality of the machined surfaces followed a pattern approximately similar to that of the machine vibrations. The actual heights of the surface waves were always smaller than the calculated heights of the ideal waves. This could be due to the effect of horizontal vibrations, but further investigation in this direction would appear to be necessary before final conclusions could be drawn.

In this connection, it must also be remembered that less resistance to horizontal longitudinal vibration would be accompanied by a reduction in tool life.

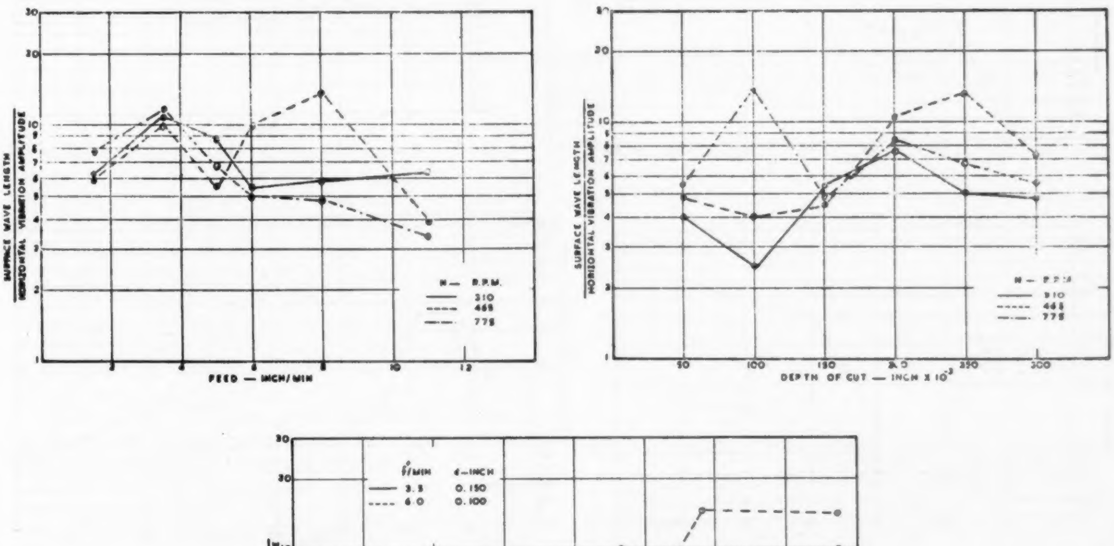


Fig. 16.

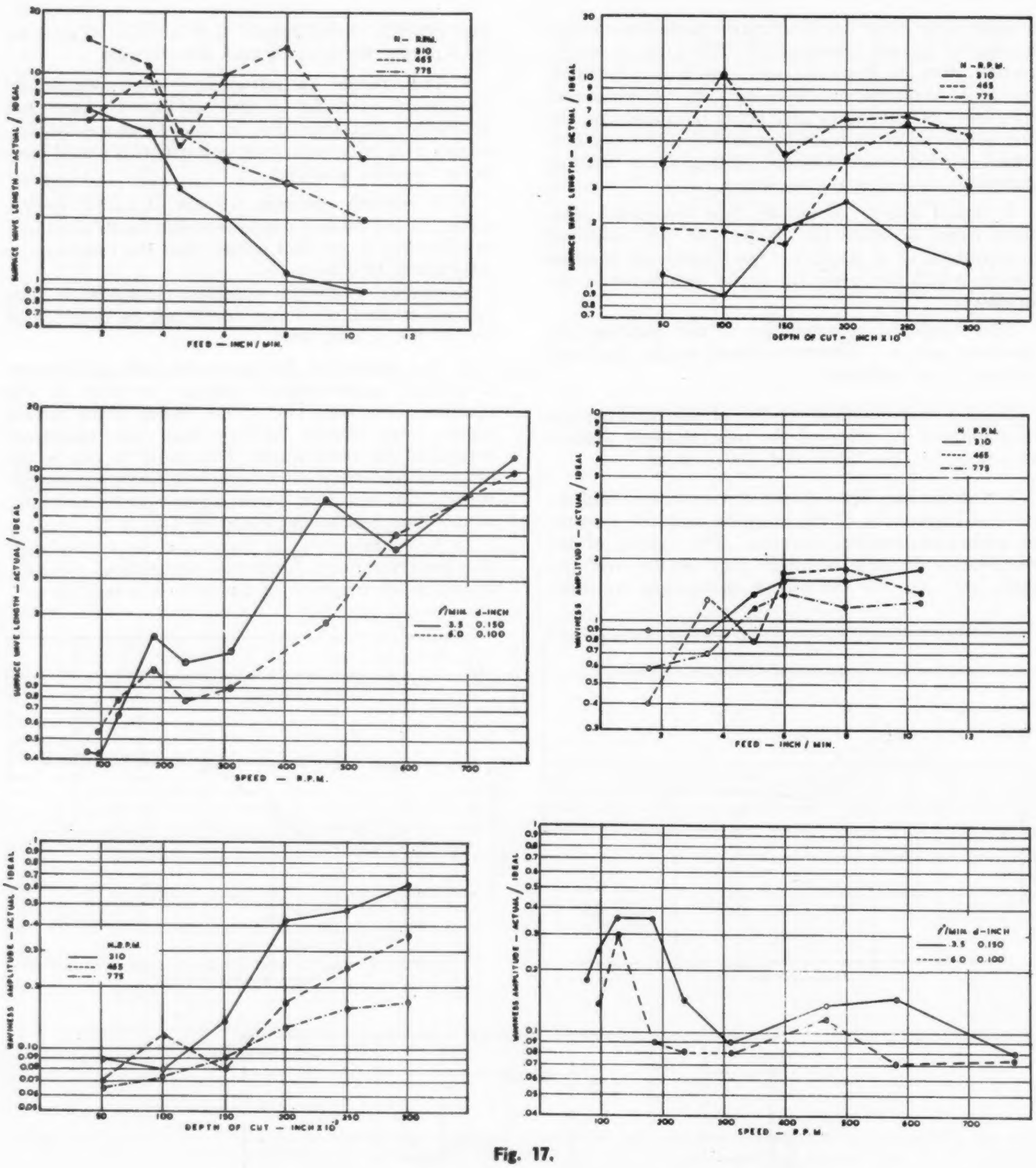


Fig. 17.

acknowledgments

The authors would like to thank Professor H. Wright Baker, Head of the Department of Mechanical Engineering, The Manchester College of Science and Technology, for permission to publish the work done in the College; Mr. A. J. P. Sabberwal, M.Sc.(Tech.), for his suggestions and contributions to the script; and all other members of the staff, who have been helpful during this work.

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COPY TURNING LATHES
(Part III)

A review by I. B. KING, G.I.Mech.E., A.M.I.Prod.E.

Assistant Education and Technical Officer,
Institution of Production Engineers.

This Paper is divided broadly into three parts: the first describing, in general terms, the basic principles used in copy turning systems; the second dealing in more detail with machines which are in current production, particularly those designed specifically for copy turning purposes; and the third presenting practical examples of how these types of machines have been used to advantage.

Part I appeared in the January Journal and Part II in the March issue.

Magdeburg Machines Ltd., Germany
Agent: Hicks Machinery Ltd., London, W.11.

A hydraulic copying attachment may be fitted to the range of Magdeburg precision production lathes, at the rear of the cross slide and at 45° to the work.

Where more rapid rates of production are required the semi-automatic lathe DH 300 is available. Of conventional layout, it may be equipped with either one or two copying slides, one located at the front of the machine, the other at the rear; the hydraulic copying unit is mounted at 45° to the work and may be fed in either direction. A third slide for recessing purposes can be mounted on an overhead rail and may be either power or hand operated.

Single, two or three speed motors can be fitted and automatic speed changes can be made while cutting. Speed changes are actuated by means of trip stops.

The machine may be modified for fully automatic operation and automatic loading and unloading equipment provided.

Menziken Ltd., Switzerland
Agent: Dowding & Doll Ltd., London, W.14.

Three types of attachments are available for converting the Menziken range of high speed lathes into copying machines. These attachments are for:

(a) longitudinal copying;
(b) transverse copying;
(c) universal copying.

On the longitudinal copying model, the hydraulic tracer controls the cross slide movement, whilst the saddle feed remains constant. For transverse copying the reverse is the situation, the cross-feed remaining constant and the tracer controlling the movement of saddle.

By controlling both longitudinal and cross-feeds, as in the case of the universal attachment, the full capacity of the machine is available for copying and as there is two-dimensional control, square shoulders can be machined.

Oerlikon Co., Switzerland
Agent: Dowding & Doll Ltd., London, W.14.

The hydraulic copying attachment Hk-v is available for fitting to a large number of standard Oerlikon lathes and can be used for either longitudinal or transverse copying, the copying slide being adjustable to a number of positions.

On the D20/25 universal lathe, which is of conventional layout, the tracer and templates are mounted at the rear, whilst the tool post is at the front of the machine. Two-dimensional control is fitted, the tracer controlling the hydraulic motors driving the cross-slide and saddle feed screws (System III).

In order that parallel roughing cuts may be taken the saddle and cross-slide travel may be limited; stops are used to limit the saddle movement and a pilot valve for that of the cross traverse.

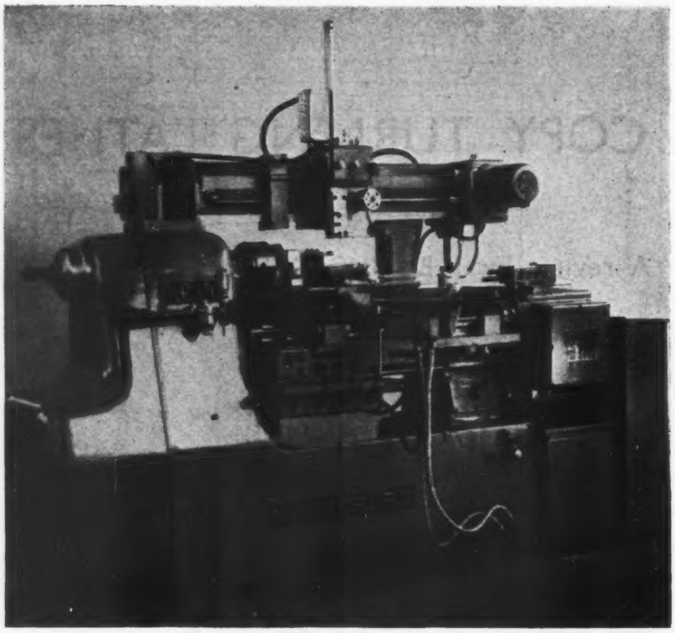

Fig. 73 (left). "Magdeburg" Model D.H. 300 semi-automatic lathe equipped with two hydraulic copy turning units and also fitted with overhead toolslide for facing or recessing.

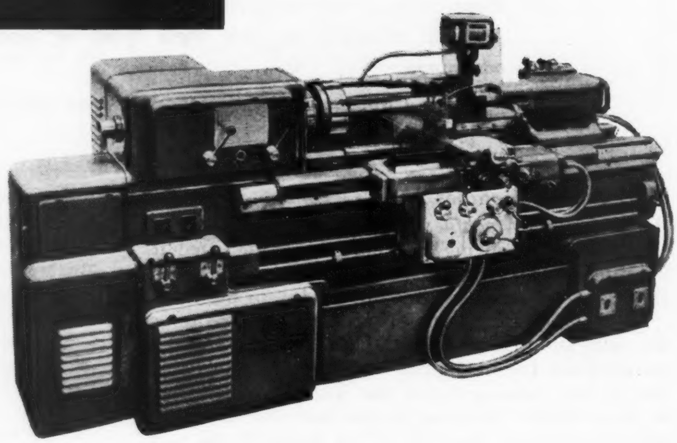

Fig. 74 (right). The Oerlikon Universal lathe Model D 20/25.

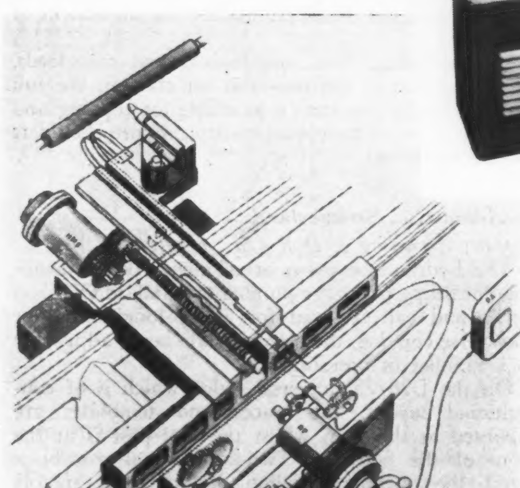

Fig. 75 (left). Diagrammatic view of the hydraulic drive to the saddle and cross slide. The hydraulic motors HMp and HMl are controlled by the tracer valve AVp. RP is a metering valve for controlling the feed rate.

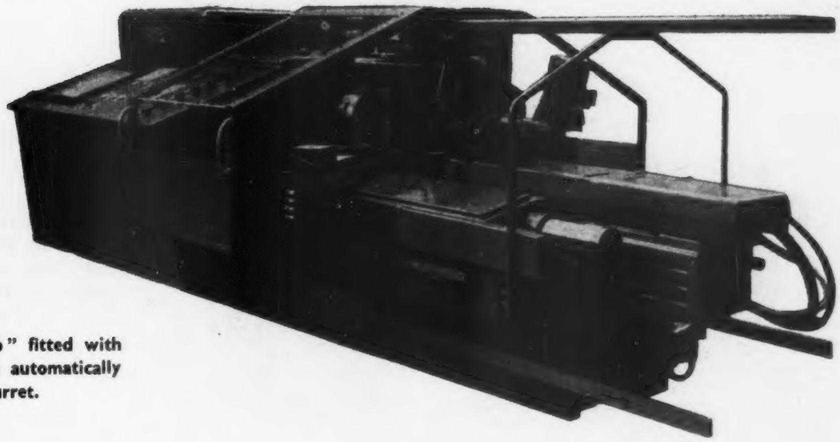

Fig. 76. A Progres "Codicop" fitted with hydraulic tracing slide and an automatically operated hexagonal turret.

Spindle speeds may be varied under load and are infinitely variable over a ratio of 1 : 4. Four speed ranges are available and these are selected by manual operation of the headstock gear box. Feeds are also variable over a wide range and selected by rotation of graduated dials.

Owing to the control of both saddle and cross-slide the full capacity of the machine is available for copy turning.

Le Progres Industriel, Belgium

Agent: Soag Machine Tools Ltd., London, S.E.11.

In addition to the range of hydraulic copying attachments for fitting to the Progres centre lathes, a copy turning lathe of advanced design is available under the name of Codicop. This machine, of unit construction, can be obtained with a wide variety of attachments and can be made fully automatic, if desired.

The hydraulic copying mechanism works on the single edge principle (System II) the slide being mounted horizontally at 45° to the workpiece. Either a round or flat template can be used, and this is mounted at the front of the machine below the copying slide.

Since the bed has four slideways, the two front ones being identical to those at the rear, a number of additional slides or carriages may be fitted, either for plunge cutting or additional turning operations. Of particular interest is the power-operated slide carrying a hexagon turret which has its own programme control, giving automatic indexing of the turret and changes of spindle speed and feed. In addition to power-operated slides, hydraulic chucking and tailstock may be fitted as extras.

A fully automatic control system is available which uses a plug board system for all machine movements, changes of spindle speeds and changes of feed.

Of considerable importance is a numerically controlled machine which has been developed in connection with l'Institut pour l'encouragement de la Recherche Scientifique dans l'Industriel et l'Agriculture. This machine is controlled through 32-channel punched paper tape. The carriage and cross-slide of this machine are driven by leadscrews, the position feed-back being provided by synchros. So far this machine is limited to parallel cuts and shoulders, together with tapers of limited slope.

Ravensburg Ag., Germany

Agent: Sykes Machine Tools Ltd., Staines, Middx.

The range of Ravensburg lathes is designed primarily for facing operations, and diameters of the order of 110 in. may be machined. These machines have been fitted with electro-mechanical or electro-hydraulic copying attachments for many years and a new addition to the range of facing lathes has been introduced, designed especially for copying, although it can be readily used as a normal lathe if desired. The copying system used is the V.D.F. Unicop electro-hydraulic type (System VII) with two-directional control of the turning carriage.

For ease of setting and in order to save space, the tracer and template are mounted separately from the carriage and move in a vertical plane, whilst the corresponding carriage movement is horizontal.

Fig. 77. Close up view of copying slide with hydraulic feed drive and programme control rails.

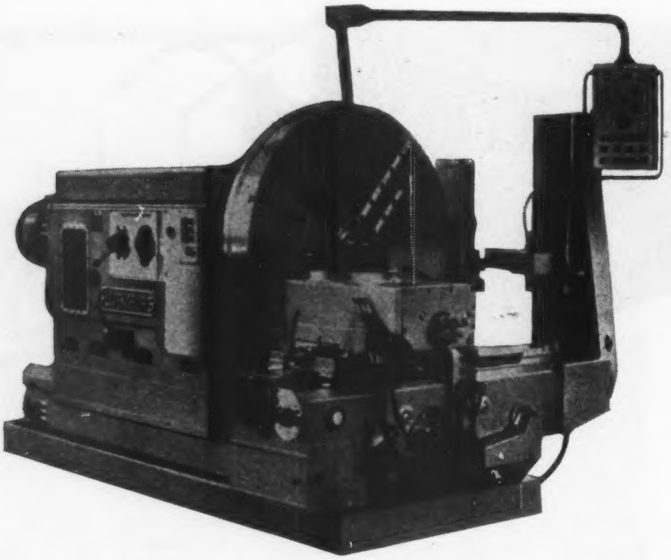

Fig. 73. Ravensburg K.H. 55 surfacing lathe fitted with Unicop copying system. Template and tracer are mounted vertically and the programme control rails may be seen under the surfacing slide.

Normally only flat templates are used but if screw threads need to be cut, a special rotating master is fitted.

Because of the hydraulic drive to the carriage infinitely variable feeds are possible, and since there are normally large diameter variations of the workpiece, constant cutting speed control is fitted. This is by means of a Ward-Leonard set with a speed ratio of 1 : 8; a servo connection between the spindle and the feed control provides for a constant feed per revolution of the spindle. Twelve speed ranges are available by a manually controlled headstock gear box.

Programme control can be fitted and the different operating movements are initiated by means of trip stops mounted on the programme control rails in front of the machine.

I.W.K. (Schaerer), Germany

Agent: Kimbell Machine Tools Ltd., London, S.W.8.

A hydraulic copying attachment may be fitted to most Schaerer lathes and a special feature of these machines is that rotating templates may be employed for non-circular copying. The use of a rotating master driven from the headstock enables the copying of non-circular dies and punches, three-dimensional cams, cam shafts and similar types of work.

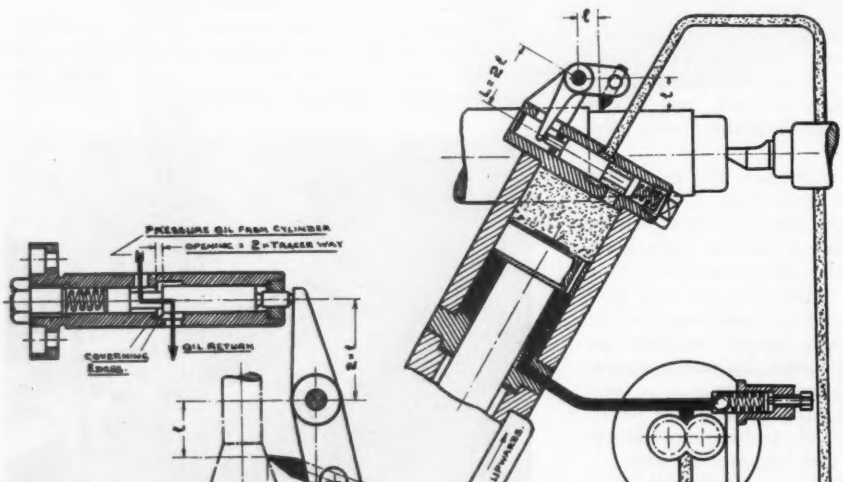

Fig. 79. The Schaerer copying system.

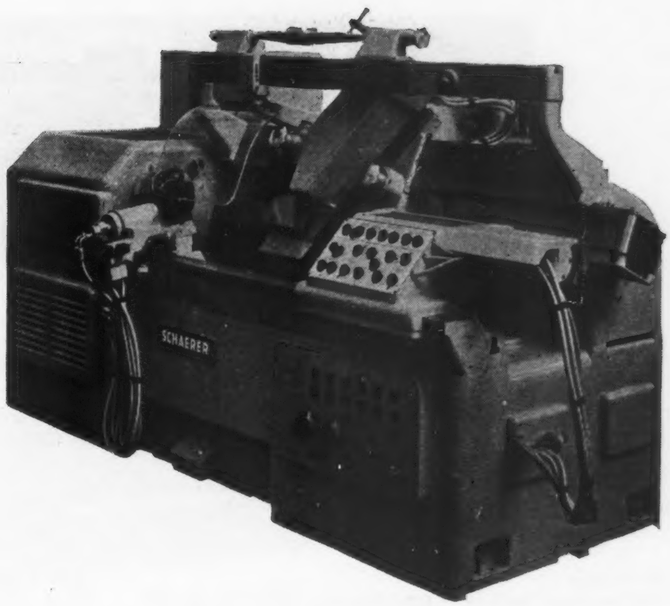

Fig. 80. Model H.K. 400 copying lathe. The control rails can be seen mounted above the slide. A power operated recessing slide is fitted at the front.

H.K. 400

The H.K. 400 is designed for the semi-automatic production of shafts and similar components and on this machine, the copying slide is mounted on an inclined bed at the rear and at 45° to the work. The hydraulic tracer works on the single-edge principle (System IIb) with the stylus so arranged as to give a 2 : 1 magnification of template changes.

Either flat or round templates may be used and if the automatic multi-cycle device is fitted, a three-position indexing flat template holder can be used, allowing three passes to be made under template control.

Spindle speeds may be changed whilst cutting, either automatically or by hand, and up to eight may be used, thus giving a good approximation to a constant cutting speed control. Feed for the copying slide carriage is by means of a hydraulically driven leadscrew; thus infinitely variable speeds may be selected and a single change may be made whilst cutting is in progress, in addition to quick traverse in either direction.

A variety of power-operated auxiliary equipment may be fitted and for machines which incorporate automatic control, the movement of the recessing slide may also be programmed.

Automatic control is by the setting up of stops on the programme control rails and initiation of the different movements is completed by contact of the stops by electrical micro-switches carried on the copying slide carriage; these in turn control the hydraulic control valves.

Vereingte Drehbank Fabriken (V.D.F.), Germany

Agent: *Sykes Machine Tool Co. Ltd., Staines, Middlesex.*

The products of this group of companies form one

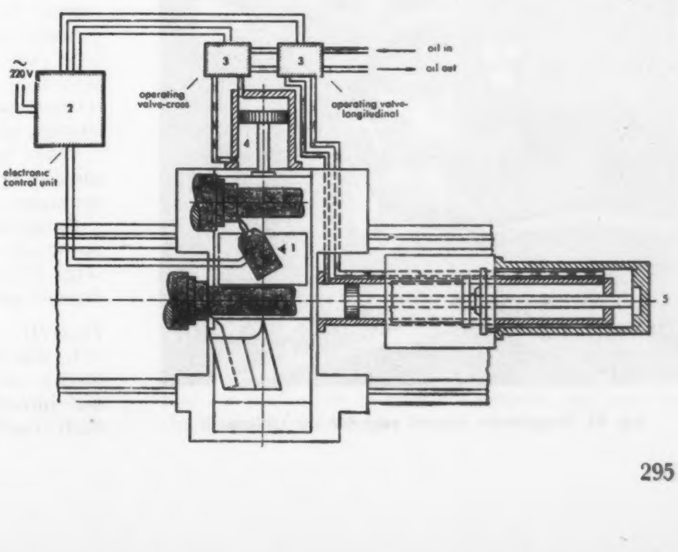

Fig. 81. The hydraulic circuit of the V.D.F. Unicop system fitted to Type I, III and IV. The electrical system is shown in Fig. 27.

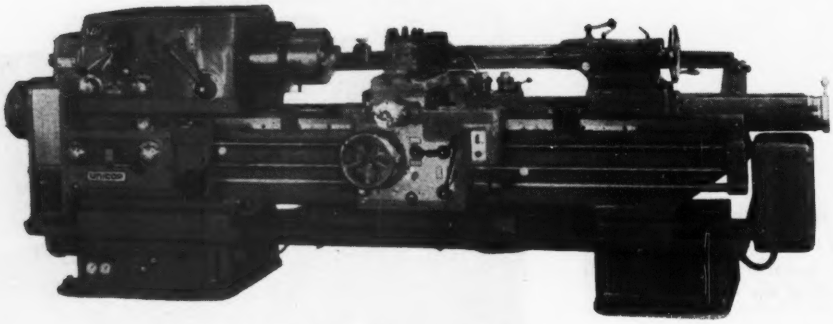

Fig. 82. Unicop I copying lathe.

of the most complete range of copying lathes available today.

Two copying systems are used, the hydraulic "Hydrokop" used on the four sizes of attachments available, and the electro-hydraulic "Unicop" system used on all the other machines.

Hydrokop

These attachments allow the complete range of V.D.F. lathes to be used for copy turning. The hydraulic tracer valve works on the potentiometer principle (System II) and is built into the copying slide. Normally this slide is mounted with either flat or round templates at the rear of the machine and the copying unit may be swivelled in order to undertake turning or facing operations. Additional attachments allow a semi-automatic cycle to be completed in which the copying slide is withdrawn and returned to its starting position.

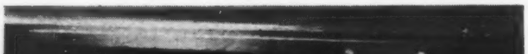

Fig. 83. Programme control rails for the Unicop IV.

Unicop

The Unicop copying range is divided into four basic groups designated Type I, Type III, Type V and Type IV. The first three are used mainly for shaft turning, whilst the fourth is designed for facing work, but can nevertheless be used for the turning of short shafts.

The Unicop system controls the movement of the tool in two directions and has a hydraulic system with electronic pre-amplification of the tracer movement. A schematic outline of the tracer system is shown in Fig. 27, and from this it will be seen that only one machine movement, that of the cross-slide, is controlled, but by the addition of the further set of contacts and arm A it can be so designed that a second axis is controlled, i.e., that of the saddle. A feature of the system is that movement of the saddle is only controlled when the cross-slide is incapable of following the template contour.

Movement of both saddle and cross-slide is by means of hydraulic cylinders and hence the length of copying which can be undertaken is limited. The cylinder driving the saddle can be seen in Fig. 82.

Type I

This model, in four sizes, will undertake both normal turning with screw cutting and copying.

Since the machine is designed for use as a normal lathe only a limited amount of automatic operation is provided: the automatic return of the saddle to its starting position, together with an automatic feed change, which may be added as an extra facility.

When copying, the feeds are infinitely variable but spindle speeds may only be changed by manual operation of the headstock gear box.

By fitting an overhead auxiliary bed a range of power or manually operated slides may be fitted (Fig. 29) and in addition, power operated chucking devices and tailstock can be used.

Type III

It was found that users of the Type I machine used it almost exclusively for copying and a model was introduced in which the lead screw and feed shaft, together with their drive, were eliminated. In

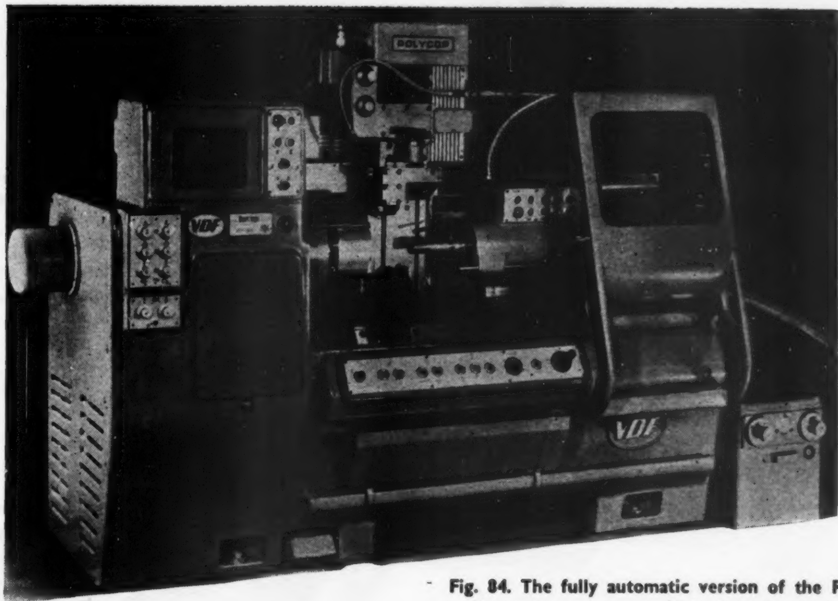

Fig. 84. The fully automatic version of the Polycop I. Automatic cycles are controlled through the plug board and trip rails. The copying slide is mounted vertically and trips are mounted on the control rails for controlling longitudinal and transverse movements of the copying slide.

addition, the maximum length of bed available is not as great as on Type I, but in most other respects it is similar. A depth of cut pre-selector may be fitted so that parallel roughing cuts may be taken prior to copying.

Type V

Where the Type I is not suitable because of its restricted length, the Type V can be used and on this machine, whilst the cross-slide is driven by a hydraulic cylinder, the saddle feed shaft is powered through the lead screw, *via* an electro-hydraulic clutch. The clutch is controlled by the tracer, so that when the cross-slide is unable to follow the template slope the clutch disengages the saddle feed, the cross-slide feeding in or out until the shoulder is cleared.

Type IV

Where there is a preponderance of face copying work, Unicop IV is more suitable than the other machines. In addition, a wide range of control cycles and attachments gives it considerable flexibility.

A special feature of the machine is that the copying slide is flat with two "T" slots running the full length, thus allowing a variety of tool holders to be mounted. Of considerable use when copy facing or flat turning is the three-way automatic indexing turret, which can be used in conjunction with a three-way template holder, Fig. 31. For longitudinal turning a two-way indexing template holder may be used in place of the three-way attachment.

A wide range of spindle speeds is available and these may be automatically varied whilst cutting to give a constant cutting speed. Feeds are infinitely variable and speed changes under load may be arranged. In addition, savings in time can be achieved by the use of skip feed and rapid return.

Where fully automatic operation is required a programme control unit may be fitted, the machine movements being selected by means of a plug board and initiated by trip dogs acting through micro-switches. The trip dogs are carried on programme control rails mounted above the machine. Where the programme may have to be repeated, templates can be made for the position of the dogs and the plug arrangements.

Where a number of set-ups are required for machining one workpiece, automatic loading and unloading and work transfer equipment may be used to link a number of machines together.

Polycop

Two machines are available and are designed for heavy duty turning where maximum metal removal is required; they are of extremely rugged construction. The copying slide, using the "Unicop" system, is mounted vertically to allow adequate chip clearance, and is similar to the Unicop IV in that two "T" slots running the full length of the slide, enable a number of pre-set tool blocks to be fitted, so that follow-on copying can be achieved. In cases where successive tools have to be used, the three-way indexing turret can be mounted to the slide.

For plunge cutting a special slideway at the front of the machine can be used to carry a number of hydraulically operated slides. These are controlled within the machine cycle and, in addition, the feed rate for each slide is infinitely variable and may be changed whilst cutting.

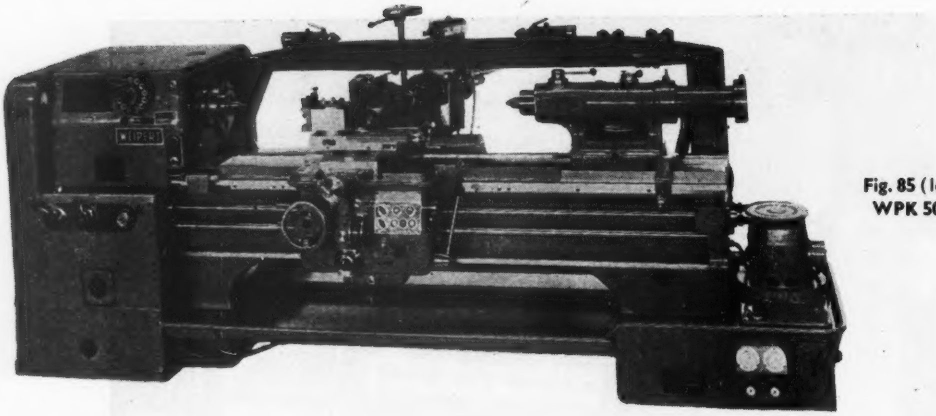

Fig. 85 (left). The Weipert WPK 500 copying lathe.

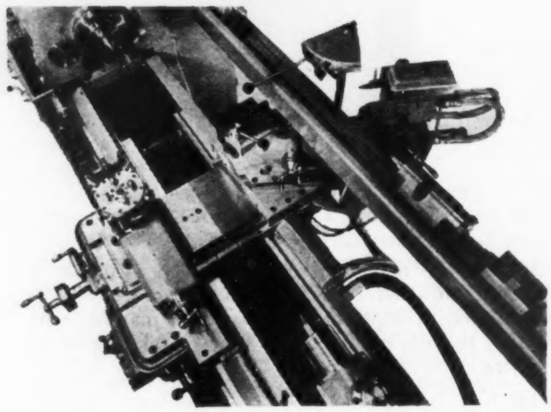

Fig. 86 (right). A view of the WPK 500 showing the tracer and copying slide.

Fig. 87. Type TPD 24 production lathe with copying slide.

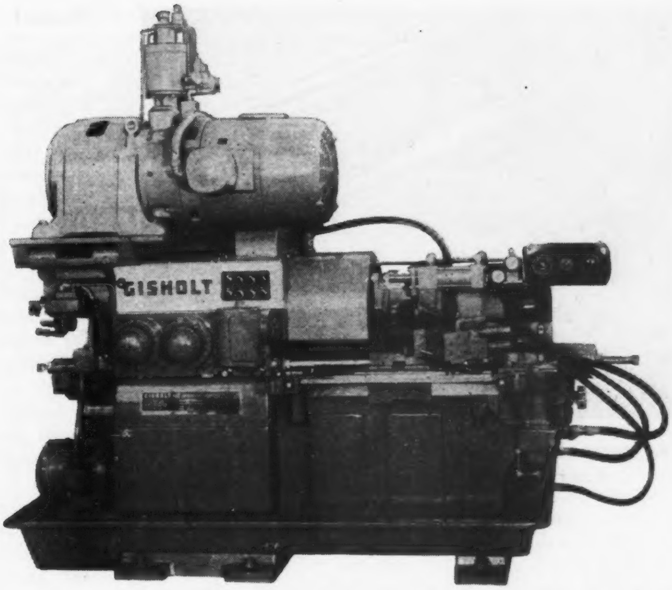

Fig. 88. No. 12 automatic lathe with tracer-controlled slide.

In its standard form the Polycop machine is fitted with an eight-step clutch drive and speeds can be changed automatically. As supplementary equipment constant cutting speed control may be provided. As on the Unicop range feeds are infinitely variable and in addition, two changes may be made during the machining cycle.

Automatic programme control may be provided and programme rails are fitted for both longitudinal and transverse movements. A separate programme rail is fitted for the boring tailstock, thus forming a completely independent unit.

F. C. Weipert, Germany

Agent: *Wickman Ltd., Coventry.*

The W.P.K. 500 and 560 are production lathes fitted with a hydraulic copying slide at the rear of the machine at 60° to the centre line, the template being mounted on a separate rail above the copying unit. For roughing or recessing the front tool post is used, and either a quick change or four-way type can be fitted. Length and depth stops are fitted to limit the slide and saddle movements. A wide range of speeds and feeds is available, being selected through a manually controlled gear box. An additional feature is the stop operated rapid return and feed reversal of the saddle. Feed reversal allows a much wider range of copying to be undertaken and spherical copying becomes possible, particularly since reverse feed is reduced by a factor of 2 : 1.

Where heavy work is being turned, power operated work holding and tailstock facilitates work handling by the operator.

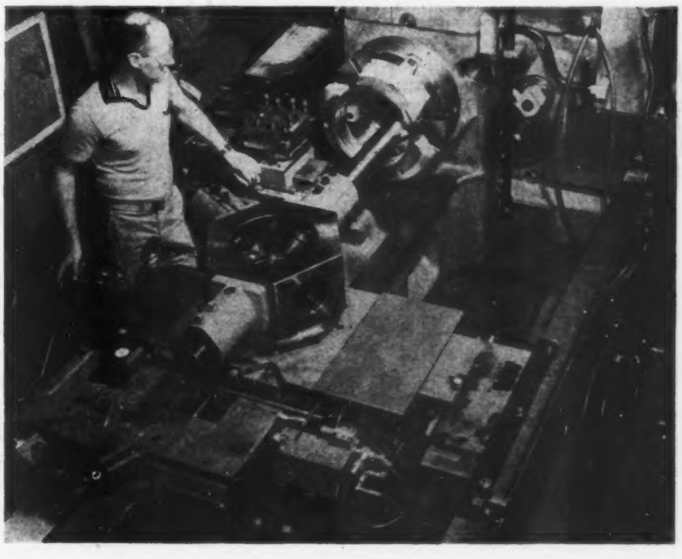

Fig. 89. Jetracer attachment fitted to a Lodge & Shipley turret lathe for a grooving operation.

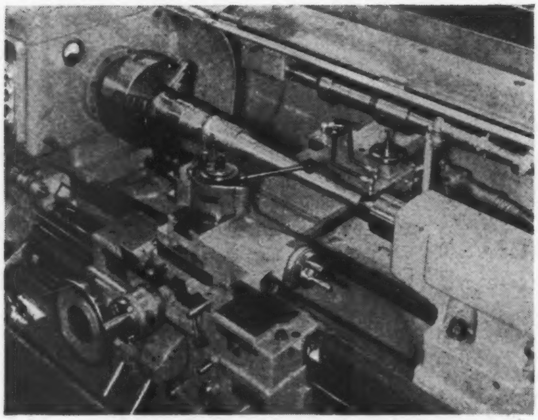

Fig. 90. General view of a Lodge & Shipley Powerturn lathe fitted with 90° Copymatic tracing equipment.

45° HYDRAULIC TRACER CIRCUIT

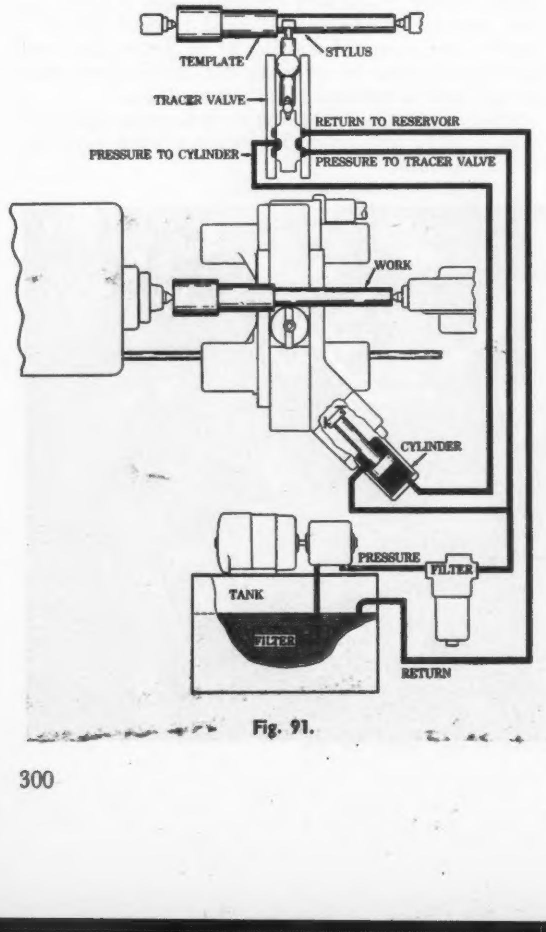

Fig. 91.

Poland

Similar developments in copy turning are taking place in Eastern European countries and it may be of interest to give brief details of some Polish machines which are available.

A machine of modern design is the TPD 24 production lathe fitted with a hydraulic copying slide, produced by the Fabryka Maszyn (Machine Building Works). The copying slide is mounted at the front of the machine, on a sloping bed, at 60° to the work centre line and the hydraulic tracer (System I), also mounted at the front, can use either flat or round templates. Roughing and finishing cuts are controlled, for length and depth, by rotating stop bars.

Hydraulic drive to the carriage allows an infinite range of speeds to be selected and when the spindle is fitted with constant cutting speed control, maximum metal removal rates can be achieved.

A machine designed primarily for the turning of shafts is the TGA 10 built by Centralne Biuro Konstnkji Obrabiarek (Central Machine Tool Design and Development Establishment); this has the copying slide mounted vertically above the work and at 60° to it. Either flat or round templates can be used with the hydraulic tracer (System II). Automatic cycles can be set up by means of stops and included with the six cut cycling device is automatic speed and feed change. Parallel roughing cuts are controlled by length and depth stops and power operated chucking and tailstock assists in loading and unloading.

American Machines

Gisholt Machine Co., Wisconsin, U.S.A.

Agent: *Burton, Griffiths & Co Ltd., Birmingham,* 33

A hydraulic tracing unit for fitting to the range of Gisholt lathes is produced and is known as the Jetracer; the tracer works by directing a high pressure jet of oil to one or other of two orifices connected to the cylinder on either side of the slide piston (see Fig. 13).

Fig. 88 shows a No. 12 automatic lathe fitted with a tracer-controlled slide and this machine may be obtained with a completely automatic cycle of operation. Feeds may be changed under load, whilst a range of pick off gears give a large number of spindle speeds.

The application of tracing equipment to larger machines is illustrated in Fig. 89 where tracing equipment has been fitted to a turret lathe and is being used for a complete boring operation.

Lodge & Shipley Co., Cincinnati, U.S.A.

Agent: *E. H. Jones (Machine Tools) Ltd., Hove, Sussex.*

There are four basic ranges of machines which can be used either for normal lathe work or copying, and may quickly be changed from one to the other. Only a front tool post is used for both copy and recessing operations, the tracer being mounted at the rear of the slide.

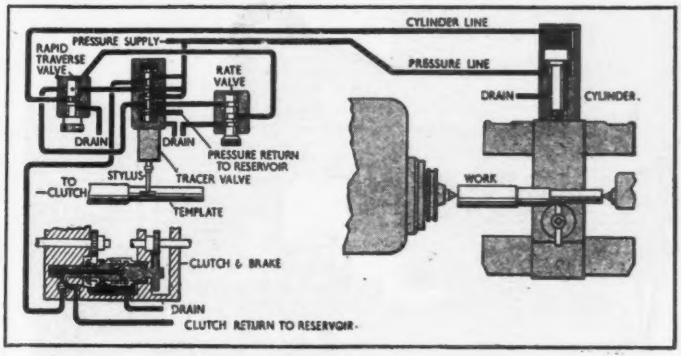

Fig. 92. Circuit diagram for the 90° Copymatic tracing unit.

45° Copymatic

A hydraulic tracing slide is mounted at 45° in place of the normal cross-slide, the power cylinder being mounted at the front of the lathe with the tracer at the rear. Normally, round templates are used and are carried on an overhead rail but by the fitting of additional attachments, flat templates can be used for either turning or facing operations.

90° Copymatic

Greater versatility is provided by the application of the 90° Copymatic equipment to Powerturn lathes. The hydraulic tracer controls both movement of the cross-slide and on-off movement of the saddle. Feed to the saddle is through conventional feed shaft arrangement, except that a hydraulic clutch is interposed between the feed box and the shaft.

With reference to Fig. 92, the tracer valve is so designed that when the stylus is not in contact with the template the hydraulic clutch controlling the feed is disengaged and the hydraulic cylinder moves the cross-slide towards the template. When the template is contacted the stylus is deflected to the neutral position and the longitudinal feed engaged. When a shoulder is reached the stylus is further deflected, disengages the clutch and engages the brake, thus stopping the saddle feed and the porting is so arranged that at the same time oil is directed to the cylinder, so that the slide withdraws from the template until the shoulder is cleared. At this point the saddle feed is re-engaged.

Longitudinal feed is controlled through the normal feed box and since the cross-slide is hydraulically powered, it is infinitely variable.

Suitable tooling allows the saddle to be fed in either direction whilst copying, thus square shoulders, facing one another, can be machined.

Universal Swivel Copymatic

The tracer mechanism is the same as is fitted to the 90° copymatic, i.e., two-dimensional control, the difference between the two machines being that the copying slide may be swivelled to 90°. This arrangement allows considerable versatility in the jobs which are undertaken and both turning and facing work can be machined with equal facility. Normally only flat templates are used and two special holders are provided, one for turning work and one for facing.

Dual Tracer

For the larger, more complex operations the Dual Tracer lathe provides 360° control of the cutting tool. The hydraulic tracer controls both movement of the cross-slide and saddle by regulating the hydraulic motors which drive the leadscrew and cross feed screw. This method of control allows the full capacity of the machine to be used for copying and templates are mounted on an overhead rail at the rear of the machine.

Monarch Machine Tool Co. Ltd., Ohio, U.S.A.
Agent: Rockwell Machine Tool Co. Ltd., London, N.W.2.

The "Air-Gage Tracer" system fitted to Monarch machines uses pneumatic amplification of the tracer movement (System V) and reference to Fig. 93 will show how changes in air pressure control the movement of a hydraulic spool valve.

This system is either fitted to standard Monarch centre lathes or incorporated into a machine specially designed for copying purposes. Layout of the copying

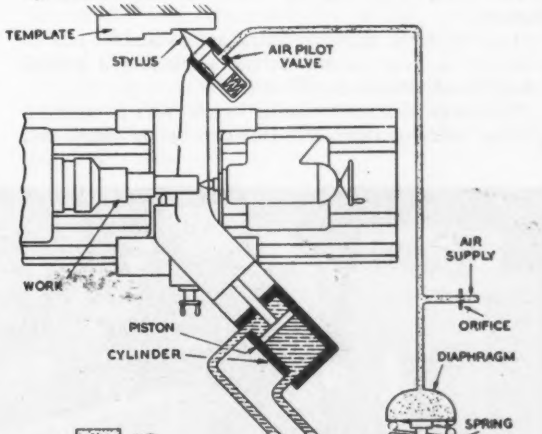

Fig. 93. The Monarch Air-Tracer copying system.

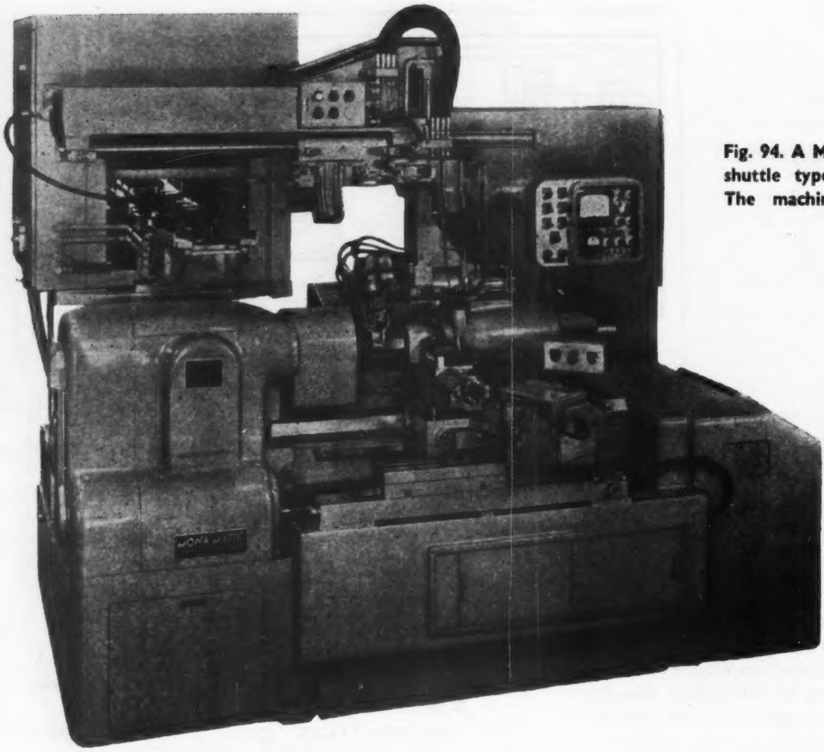

Fig. 94. A Monarch Mona-Matic 21 fitted with shuttle type loading and unloading device. The machine is completely automatic in operation.

slide is such that the tracer and template are at the rear of the machine, whilst the copying slide and tool post are mounted at the front.

Where it is intended to have the copying system built-in prior to delivery of the centre lathe, an automatic cycle unit can be fitted as an additional feature.

Two types of copying slides are available, one in which it is fixed at 45° to the work and a second which is adjustable to 45° and 90°.

For large diameter facing work where constant cutting speed is desirable, this can be provided and is controlled by a special template. Feed variation is also available and is simply controlled by the rotation of a dial.

Model 21, *Mona-matic*

This machine is fully automatic and is fitted with a programme control circuit. On this model the copying slide is permanently fixed at 60° from the work axis, with the template mounted below the copying unit on a slide fitted with micrometer adjustments to ensure accurate template alignment.

Fig. 95. The Sundstrand 14 lathe with punched card control. The stack of punched cards is placed in the control cabinet and after the start button is pressed, the cycle is completely automatic.

A separate power-operated slide is mounted at the rear for recessing and the cycle of operation of this slide is completely separate, but is initiated by the normal programme control circuits.

A variety of spindle speeds is available by means of pick-off gears or alternatively, if a two-speed motor is used, the change from high to low speed in a ratio of 2 : 1 may be achieved automatically. An additional feature is the provision of constant cutting speed control. Feeds are infinitely variable and depending on the number of cutting cycles required, up to four different feeds may be used on any one pass.

Depending on the amount of metal to be removed the machine can be set to take up to four passes over the work, the last two cycles being under template control, the others being parallel cuts.

When fitted with programme control up to 24 different operations may be programmed by means of cams mounted on an indexing shaft; each cam can be fitted on the shaft in any one of 20 angular positions and, by this means, the time at which the different machine movements take place is determined. Indexing of the cam assembly is accomplished by means of electric signals produced by the contact of micro-switches with dogs mounted on programme rails at the front of the machine.

The programme control will also integrate into the cycle of operations the automatic loading and unloading devices.

Sundstrand Machine Tool Co., Rockford, U.S.A.
Agent : Rockwell Machine Tool Co., London, N.W.2.

The four ranges of standard Sundstrand automatic lathes can be fitted with multi-cycle hydraulic tracing equipment, and all three cycles are under template control. The tracer attachment is fitted on the front turning slide, at 45° to the work, and the rear slide is used for facing cuts. When more than one cycle is required the length and depth of cut of each cycle can be set by the indexing stop plate.

Model 14 T

Where greater machine versatility is required the 14 T lathe offers advantages over those fitted with attachments. The tracing slide is mounted on a vertical slideway and at 45° to the work. Where facing cuts have to be taken a separate unit is mounted below the work and this arrangement of the machine components allows ample clearance for chip flow.

The hydraulic tracer follows a flat template and up to four cycles can be taken, all under template control. In order that tool changing may be reduced to a minimum, the tracer slide is fitted with a two-way indexing turret for rough and finish turning.

A variety of spindle speed ranges may be selected by means of pick-off gears or by the fitting of 2, 4 or 8 speed heads. Feeds are infinitely variable over a wide range.

Completely automatic cycles are chosen by means of selector switches mounted on the headstock and the movements are initiated by dogs fitted to control rails.

Owing to the open front design of the machine, automatic loading and unloading together with chip disposal equipment may be fitted.

Model 14

A development of the 14 T is the model 14 lathe, which is fitted with punched card control. This machine is designed for the machining of stepped shafts from numerical information fed in by means of 45-column punched cards. Where curves or tapers are required a cam is necessary for this portion of the cut. The control system, developed by G.E.C., accepts the digital information from the punched card and converts it into a voltage analogue. This is amplified and used to drive the cross-slide and saddle, the position of the slide being measured by a synchro and compared with the voltage input (the elements of a feed-back control circuit are illustrated in Fig. 3). The voltage analogue presented to the amplifier corresponds to the difference between the actual and the required position, and movement of the tracing slide is such that the error is reduced to zero.

Two control circuits are fitted, one for movement of the saddle, whilst the other is for movement of the cross-slide which is mounted in a vertical plane and at right-angles to the work. Accuracy of the system is such that tolerances of $\pm$ .0005 in. on diameters can be held whilst lengths are within .005 in. By the fitting of such a control system the full capacity of the machine can be utilised for "copying" purposes.

To facilitate roughing and finishing, a two-position indexing turret is fitted to the cross-slide and this is automatically indexed at the appropriate part of the machining cycle.

Spindle speeds may be changed at each diameter to ensure maximum cutting efficiency and up to eight speeds may be used by means of pick off gears. The saddle drive motor is hydraulic and consequently feeds are infinitely variable. Skip feed and rapid return are features of the cycle.

As in the case of the 14 T, automatic loading and unloading, chip removal and gauging equipment may be fitted and these will also be controlled by the punched cards.

Seneca Falls Machine Co., Seneca Falls, U.S.A.
Agent : Gaston E. Marbaix, London, S.W.11.

Model 'Q' automatic lathes are available in two sizes, the 'AQ' being slightly larger than the 'LQ' and also fitted with a more powerful headstock motor.

The carriage for the copying slide is mounted on a vertical headstock bedway with the slide being mounted at 45° to the work.

An unusual system is used which employs torque amplifiers to drive the copying slide, an electrical tracer being in the form of a transducer (System VIII) the central core of which is mounted to the tracer. Movements of the stylus and core create a voltage which is amplified and controls the speed and torque of a low power servo motor. This motor is connected to a mechanical torque amplifier and thus

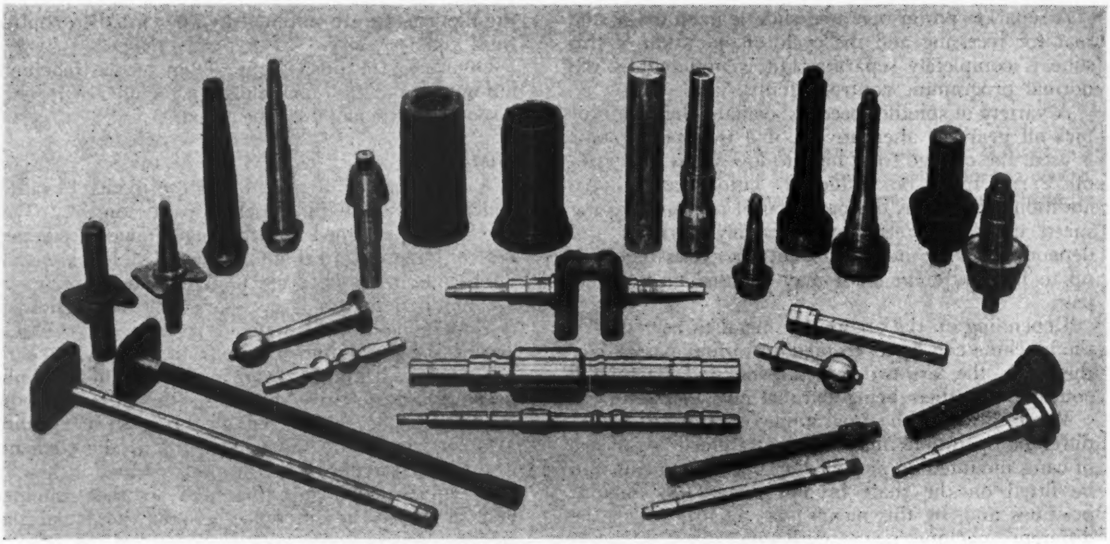

Fig. 96. Examples of workpieces machined from bar or forgings.

the movements of the servo motor are converted to an output at a high torque level. The output shaft is connected to the feedscrew of the copying slide.

Where considerable quantities of stock need to be removed, parallel cuts can be taken. The dimension of these cuts is extremely easy to set up in that only a number of dials need be rotated to indicate the required diameter and length. The control system will accommodate up to 10 passes, the final one being under template control, and the control system will also automatically change the speed and feed. When loading and unloading devices are fitted, these will be incorporated in the cycle.

A number of recessing or turning slides may be fitted if required and more than one copying unit, either right-hand or left-hand, may be used.

use of copying lathes

Many of the machines which have been described in previous sections are suitable, in the main, for the turning of shafts and similar types of products and Fig. 96 illustrates a wide variety of this type of article which have been machined on copying lathes. A survey by one manufacturer revealed, however, that there is a larger percentage of work of the ring or disc type, and for this it is very often desirable to

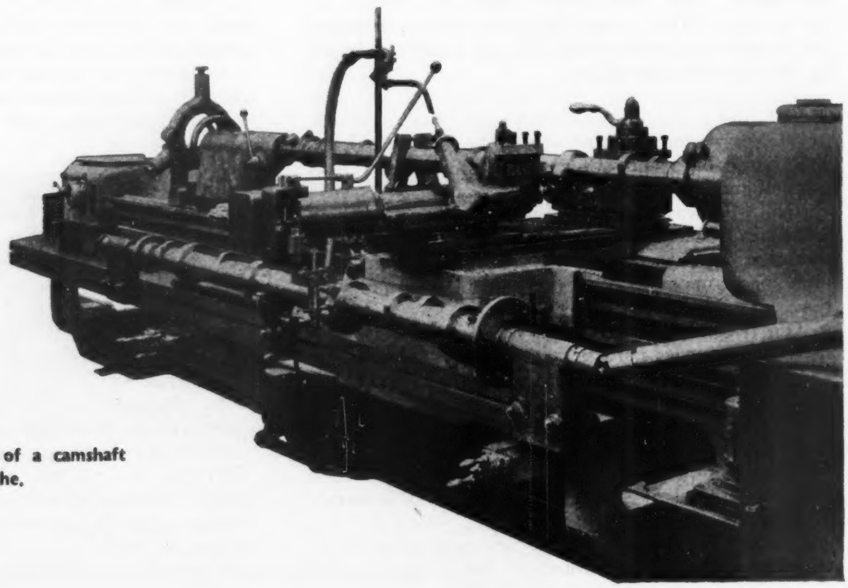

Fig. 97. Non-circular turning of a camshaft on a Schaerer lathe.

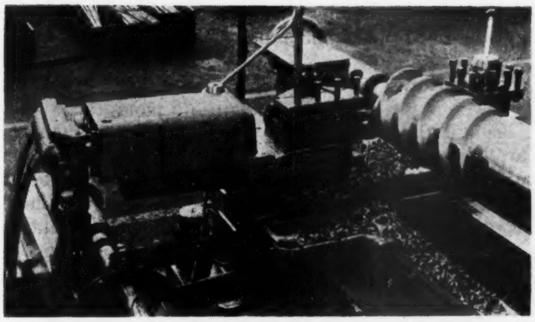

Fig. 98. A further example of non-circular turning, using a plate cam.

use a machine specially adapted for the purpose. In this case, either the use of a turret head on the copying slide or twin copying slides, fitted either side of the centre line, ensure rapid metal removal and a high rate of production, particularly when the machine is fitted with an automatic control cycle. Where such a control system is fitted, experience will determine the number of parts which have to be produced to ensure that it is economical to set up the fully automatic control cycle, and it will have been noted that in some cases the machine manufacturers have adopted such devices as punched cards or pre-set stop plates to allow rapid changes of set-up. It is claimed by some manufacturers that it is justifiable to use a completely automatic cycle for as few as five pieces.

The fitting and use of copying attachments to centre lathes is undoubtedly an economic proposition, particularly where small batches are being machined, as where close tolerances have to be held, e.g., on bearing diameters, these can be either finished by hand control of the lathe or finish ground on another machine.

Many users have found the use of a copying slide of value when undertaking high speed threading operations up to a shoulder, as the use of the copying slide enables the threading tool to be rapidly withdrawn automatically if a shouldered template is fitted in the appropriate position.

Non-circular work very often presents a number of manufacturing difficulties, particularly where the number required is small. By using a rotating master accurate duplicates can be made from an existing part or, in some cases, a plate cam can be used. Mould manufacture can be facilitated by using this method and the technique of reverse copying is well illustrated in Fig. 99.

The use of copying equipment on production machines such as turret or capstan lathes has not been fully exploited and its adoption will often eliminate the necessity of expensive tooling. It is significant that automatic copying lathes, fitted with indexing turret or tool posts, are extensively used on the Continent in place of capstan and turret lathes.

Since the turned form is developed from a template, it follows that to a certain degree the final accuracy of the component will depend on that of the

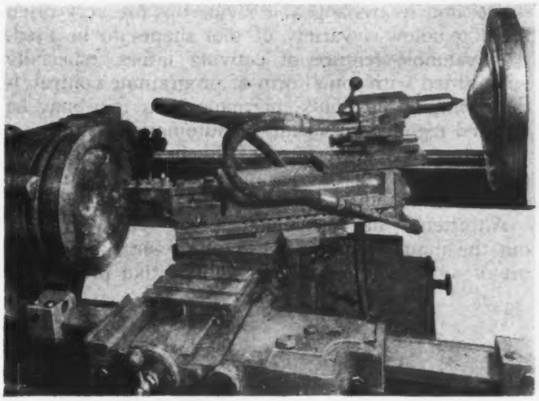

Fig. 99. Reverse copying of a die set on a J.E.B. OC420 G.T.

template. Since many tracers are responsive to movements in the order of .0002 in. it is obvious that care must be taken to ensure that not only must the template itself be accurate, but that setting up is also accurate. Usually the template holder is provided with micrometer screw adjustment.

Where long templates are being used, particularly if the tracer and template are in the vertical plane, checks should be made to ensure that the template holder or round master is sufficiently stiff to eliminate errors due to sagging.

It may be possible to overcome this difficulty in the case of flat templates by making it in a number of parts and adjusting each part separately to ensure accuracy in the final component.

Since most copying lathes use a single point cutting tool in a long uninterrupted cut, it is necessary to use tipped tools of large section so that heat may be readily absorbed and dissipated. As has already been shown, pre-set tool holders can be fitted and setting devices are supplied either as a fixture on the machine or as a separate item.

To ensure ease of design and manufacture of templates the stylus and tool tip are normally of the same

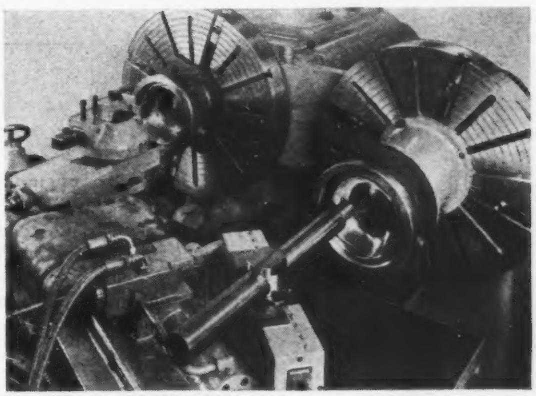

Fig. 100. A Schaerer lathe equipped with a rotating master holder being used to copy an existing mould.

shape, and interchangeable stylus tips are very often fitted to allow a variety of tool shapes to be used.

A valuable feature of copying lathes, especially when fitted with some form of programme control, is their extreme flexibility, particularly as they may be coupled together by means of automatic loading and unloading devices. Because of this flexibility write-off periods may be very much longer than for specialised machine tools, say, of the transfer type.

An attempt has been made in this review to bring out the main points of the design, construction and use of such machines and it is hoped that production engineers will thereby be encouraged to consider the possibilities of such machines.

case studies

Two case studies are given on pages 307 - 308.

In addition, it should be noted that many machines are being adapted to numerical control or control by means of punched tape, etc., and several models have been announced over the last few months. These are mainly of American or Continental origin, and it is likely that there will be significant developments in this field in the near future.

acknowledgments

The author would like to thank the many manufacturers and agents for their generous help in providing information for this review, which was sponsored by the Institution's Papers Committee, who gave much help and guidance.

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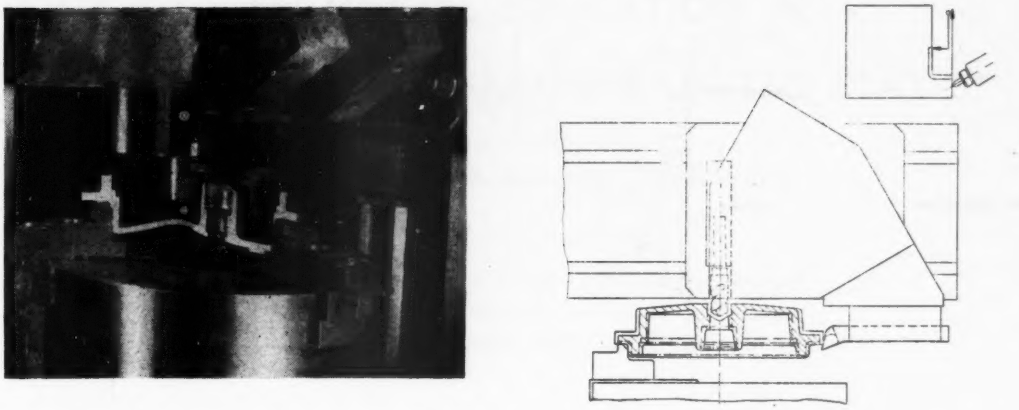
CASE STUDY A (see facing page)

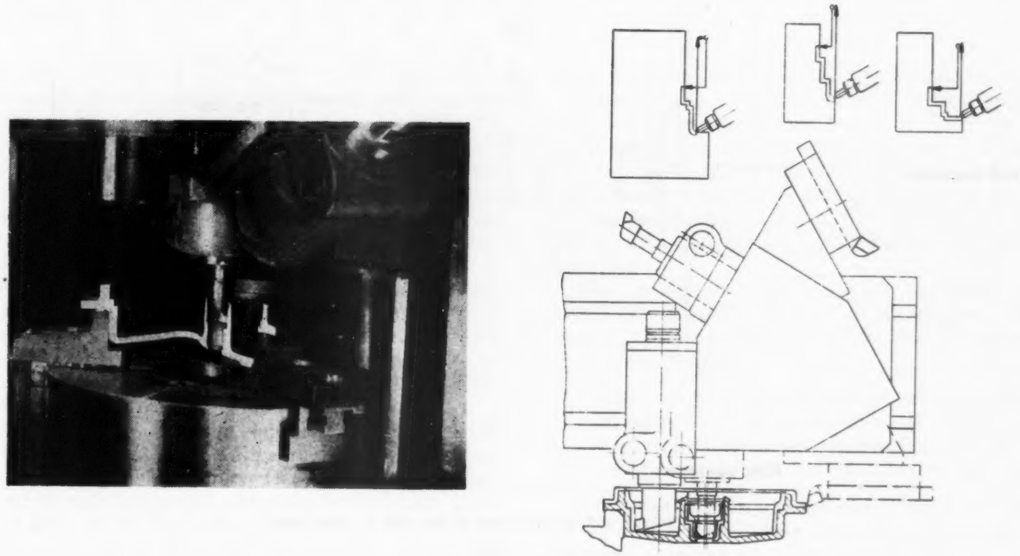
This cast iron brake cover is finished machined in three settings on the Unicop IV, with one man operating two machines. Total production time is 12.7 min. (9.4 min. machining time, 3.3 min. idle time).

The bearing diameters are finished machined during the cycle.

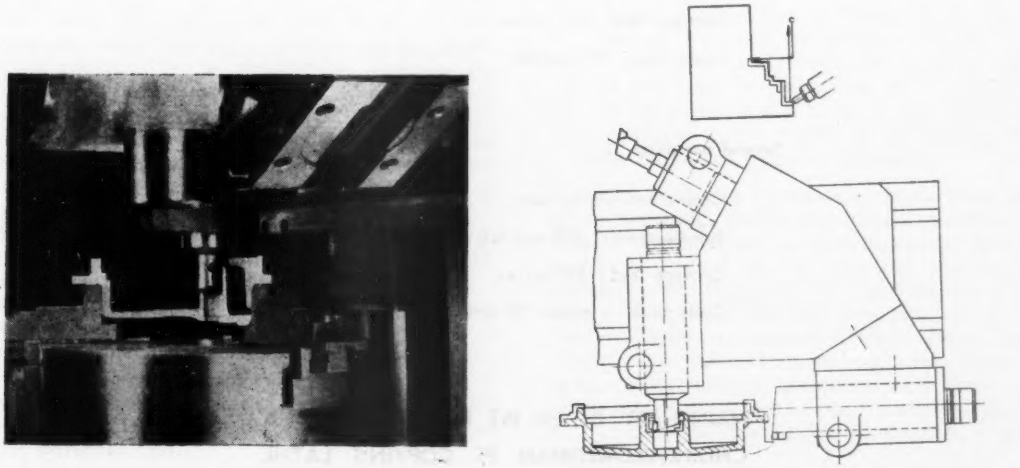
Three stages in the working cycle are shown in the photographs, whilst the tooling set-up is outlined in the drawings.



1st setting



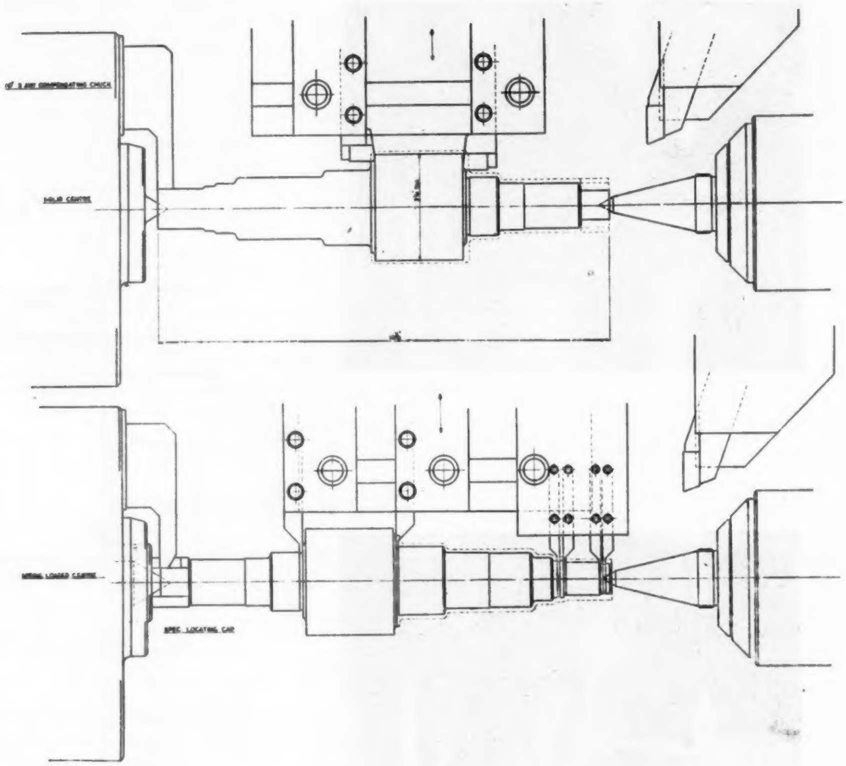
2nd setting



3rd setting

First operation

Second operation



First operation

Straddleface and profile turn short end — two cuts.

Spindle speeds : 430 and 870 r.p.m.

Carriage feed : .015 in./rev.

Cycle time : 54 seconds.

Second operation

Groove and profile turn.

Spindle speeds : 870 and 430 r.p.m.

Carriage feed : .015 in./rev.

Cycle time : 1 minute 10 seconds.

MAINSHAFT IN EN 353 MACHINED ON A CHURCHILL-REDMAN P5 COPYING LATHE

TECHNICAL EDUCATION IN CANADA, BRITAIN AND THE UNITED STATES*

by A. E. THOMAS, B.Sc.(Eng.), B.Ed., P.Eng.

Director of Mechanical, Metallurgical and Aeronautical Technologies at The Ryerson Institute of Technology, Toronto, Ontario.

IN Ontario, where technicians in the engineering industry have collected from many parts of the world and have such diversified educational backgrounds, there is a fundamental need for some more or less clear picture of comparative technical levels. In my own experience, I have found that a simple misunderstanding of the Canadian viewpoint can so easily cause feelings of frustration, and even resentment, among newcomers to Canada.

For our group here, I think the most helpful approach to a difficult subject would be to compare directly the educational situation in Ontario with that in the United Kingdom, with some little mention of that in the U.S.A.; for Canadian education, while being a copy of neither, is influenced by both.

Dealing first with the question of professional status, the normal route to this, in all three countries, is, of course, a University Degree in Engineering together with approved industrial experience. Now some 30% of all high school graduates in the U.S.A. proceed to some type of college education: the corresponding figures for Canada are 7%, and for Britain about 5%. It follows that there are proportionately more degree men available in the States. But, of course, there is considerably more to the picture than just numbers. There is a very wide diversity in the levels of the U.S.A. University degrees and, although some of them may well be considered among the best in the world, there are many others that the Americans themselves admit to being of a much lower standard.

The Canadian University Degree in Engineering, requiring four years' work with entry at Grade XIII, compares with the British equivalent.

There is one important point to bring out here. Generally speaking, the mass of engineering work is done, not so much by the top layer of superlatively-trained engineers, but essentially by high-level technologists whose work lies between the top level men and the skilled craftsmen. Some of these men may have University degrees, some may not, but they are all specifically trained in their particular fields. It is likely that the number of men of this calibre produced by the huge educational output of the U.S.A. has given such originality and vigour to American industry.

This point was well made by the joint Anglo-U.S.A. Productivity Team that investigated the set-back in British industry after the War. I quote from their 1951 Report:

> "The outstanding difference between the two countries in the production of scientific and engineering personnel for industry is to be found at the level of the Americal first degree (B.S.)."

In connection with this Report, Stephen Cotgrove in his recent book "Technical Education and Social Change" makes the following comment:

> "If it is assumed that the British equivalent is the Higher National Certificate, America is producing more than three times as many engineers at this level in proportion to population size. At the higher levels, however, the British output is proportionately higher in engineering, though the output of scientists is lower."

We know that in Canada the engineering industry is, on the whole, tied to the colossal American combines. In Ontario, for example, it does not take much searching around to see that our engineering is essentially that of production, the basic research and design being done, for the most part, south of the border. There are now in Ontario something like 18,000 registered professional engineers. There seems to be no shortage now, nor does it seem likely, in view of the present campaign by the Universities, that there will ever be a shortage in Ontario of high-level engineers.

*** An address given to the Canadian Section of The Institution of Production Engineers at their Annual Dinner held on 19th November, 1959.**

Let us examine the position here at the level just below that of the Canadian University degree. This will be the level of the technologist, the man trained in the application of engineering theory to actual industrial practice, whose training is such that he interprets the language of both the profesisonal engineer and the craftsman. In production such a man is in the nature of a key man: in Britain, this level is largely filled by the National Certificate graduates.

In Canada, as you know, the engineering profession with all the rights and privileges pertaining to it by law is governed by the Association of Professional Engineers, under its Charter. In Ontario, this body has recently taken an original and fundamental step in classifying and defining all grades of engineering technicians below the level of the professional engineer. There now exist in Ontario four distinct technical levels: Technician, Grades I, II and III, and Technologist. The last title is available with suitable industrial experience to possessors of the Higher National Certificate with endorsements. The fact that these qualifications gave entry to professional status until quite recently indicates the high level of the Technologist. The Technician grades are steps up to this.

Entry to all these levels is open to anyone working in the engineering industry who is prepared to sit the required examinations. A ladder has been provided in the profession which may be climbed by attendance at evening classes in almost any major city. Full-time training up to the Technologist level is given at the Institutes of Technology which are run throughout the Province by the Department of Education. The largest of these is Ryerson, which is in Toronto, but others have been established in Hamilton, Ottawa and Windsor.

This framework of contiguous status is in its entirety comprehensive enough to cover the whole field of engineering, but it is barely a year old and its impact upon industry in Ontario has yet to be felt.

the apprenticeship scheme

In Britain there is the well-established apprenticeship scheme. With part-time day release or evening classes an apprentice can, through the examinations of such bodies as the City and Guilds of London or the Union of Lancashire and Cheshire Institutes, gain accreditation as a skilled tradesman. Alternatively, he can enter upon the National Certificate Course and, with a bit of luck, obtain the Ordinary National in three years and the Higher in another two. With further endorsements and the appropriate industrial experience, he can eventually apply for Associate Membership of the professional engineering institutions.

This road, although it is a long one, is open to him. How does it compare with what we are doing in Canada? You may well ask why something similar has not been adopted here.

According to Dr. Venables, the Principal of the Birmingham College of Advanced Technology, who recently visited us at Ryerson, other schemes are being tried out today even in Britain. He estimated that only one in five who started, finished the O.N.C. in the allotted time, and only one in six the H.N.C. Of course, many drop out or transfer to trade courses early in the race, for with the present high standing of the skilled tradesman, the tedious National Certificate Course is not always the path of wisdom. Even of those who complete the course, less than half usually pass at the Ordinary level, although the percentage rises to 60 or 70 for those who stick it out to the H.N.C.

the National Certificate scheme

This National Certificate scheme, which since 1922 has done so much to promote technical training at the intermediate level, has proved wasteful and in other respects disappointing in Britain. It is not so well suited to our conditions in Canada, requiring as it does the complete co-operation of industry. The extremely narrow scope of the course seems to be pushing the British educational trend in the direction of broader schemes offered in the Regional Colleges and the Colleges of Advanced Technology. Nevertheless, it still supplies the largest number of intermediate technologists.

(*Mr. Thomas at this point made reference to two charts; one reproduced from Dr. Venables' book, "British Technical Education" by kind permission of the author, and another prepared by Mr. Thomas. Both charts showed the routes from school to technical qualification, the first in the U.K. and the second in Ontario.*)

You will note that we also have in Ontario a sandwich scheme being run at Waterloo College. Entry here is at Grade XII (not Grade XIII) and the sandwiching consists of three months in college and three months in industry over a period of six years. A degree is given. One important difference is that the Ontario scheme is "college-based", while the United Kingdom schemes are in general "works-based" and financed by industry.

You can see also that Ryerson and its sister Institutes of Technology are destined to fill the gap between the Technical Schools, where trades are taught as such, and the Universities. The courses are full-time day and run from September until May. Entry is at Grade XII (G.C.E. O).

Although these Institutes do not provide free education they are rather heavily subsidised by the Department of Education, and the fees, as opposed to those applying at the Universities, can be considered as being within the reach of most parents.

The level of technological training follows in many respects that of the Higher National Certificate Course, but it is much broader in its scope. At a fairly rough estimate, beginning at the equivalent of our Grade XII, the student at Ryerson will do some 2,600 hours of study. whereas in the National Certificate Course the equivalent number of hours in part-time day release may range around 1,400. It follows that we have more freedom to broaden our syllabus and introduce some of the humanities. In some subjects, say, Thermodynamics in the Mechanical Course, we do not attempt to reach the H.N.C. level, as we feel we do not need this particular subject so much here,

and can strike a better balance by introducing such a subject as Machine Design. I have laid out for you the syllabus of the Ryerson course in Mechanical Technology and a comparative syllabus of the Mechanical H.N.C. At present we are running the following technological courses at Ryerson: Aeronautical, Architectural, Chemical, Civil, Electrical, Electronic, Gas, Instrument, Mechanical and Metallurgical.

And what of adult education? There is in Ontario a wide range of educational facilities for technicians already employed in industry. The Department of Education, working in conjunction with the Association of Professional Engineers, has organised the curriculum of a series of "Advanced Technical Evening Certificates". Classes for these Certificates are held at the Institutes of Technology and at Technical and other schools throughout the Province. Teachers are drawn both from the Department and from local industry. Graduation at the various levels of these Certificates will enable the student to qualify for the Technician standing recognised by the Association of Professional Engineers. The scheme is only a year old and not as widely known as it should be. For those who are interested, details may be had on application to the Association of Professional Engineers of Ontario, 236 Avenue Road, Toronto.

With approved experience, professional engineering status may be obtained in Ontario by sitting the Association examinations. Evening tutorial classes for candidates are held at Ryerson. This road, however, is long and arduous, as it is in Britain, and as it must necessarily be anywhere.

Although a tight apprenticeship scheme is not established in Ontario as it is in the United Kingdom, nevertheless the large number of technical and trade schools in Toronto and the main industrial centres give instruction both in the day and in the evening in all the various trades. It can be seen, therefore, that there is ample scope for any engineering technician in Ontario to improve his position through study. The facilities are here if he has the ambition and the will to take advantage of them.

MECHANICAL TECHNOLOGY PROGRAMME OF STUDIES

FIRST YEAR

Subject	*Hours per week* *Lecture*	*Laboratory*
Chemistry	3	2
Electricity and Magnetism	3	2
Engineering Drawing	–	4
English	4	–
Mathematics	5	–
Physics	3	2
Physical Education	–	2
	18	12

SECOND YEAR

English	3	–
Mathematics	4	–
Economics	2	–
Applied Mechanics	4	2
Mechanics of Materials	3	–
Metallurgy and Welding	2	5
Manufacturing Processes	2	3
	20	10

THIRD YEAR

English	2	–
Mathematics	4	–
Mechanics of Materials and Machines	4	2
Machine Design	–	5
Applied Thermodynamics	2	2
Tool Design	–	2
Metrology	–	2
Mechanics of Fluids	2	2
Technical Report		
	14	16

TYPICAL DAY RELEASE

HIGHER NATIONAL CERTIFICATE SYLLABUS

One day and one night a week, over five years (without endorsements)

S1	
Engineering Drawing I	2
English I	2
Engineering Science I	*2
Mathematics I	2
S2	
Engineering Drawing II	2½
English II	1
Engineering Science II	*2½
Mathematics II	2½
S3 (O.N.C.)	
†Applied Heat III	*3
†Applied Mechanics III	*3
†Mathematics III	3
A1	
Materials and Machines IV	*3
Mathematics IV	3
Applied Thermodynamics I	*3
A2 (H.N.C.)	
†Strength of Materials	*3
†Applied Thermodynamics II	*3
†Theory of Machines	*3

In a sixth year such endorsements as Industrial Administration, Works Organisation and Management, Work Study, etc., may be taken.

† *These examinations are assessed by the Institution of Mechanical Engineers.*

* *About one-third of the time for these subjects may be allocated to laboratory work.*

COUNCIL NOMINATIONS

NOTICE OF COUNCIL ELECTIONS 1960-1961

NOMINATIONS

(a) In accordance with Article 43, nominations are invited to fill *nine* vacancies for Elected Members to serve on Council for 1960 - 1961 (i.e., eight Members and one Associate Member).

(b) Before candidates are nominated for election, their consent must be obtained.

(c) Candidates for election must be nominated in writing by three *Corporate Members of the Institution.

(d) In addition to nominations as in (c) each Section Committee may nominate one candidate.

(e) The nominees must give the full Christian names (or forenames) together with respective addresses of the person or persons they are nominating.

(f) The nomination must be accompanied by brief biographical notes of the person or persons who have been nominated.

(g) Nominations must be set out on a separate sheet of paper and not included in a letter dealing with other subjects.

(h) Nominations must be contained in a sealed envelope marked "Council Nomination".

(i) Nominations must reach the Secretary at 10 Chesterfield Street, Mayfair, London, W.1, not later than Monday, 16th May, 1960.

(j) The members listed below are due to retire and are not eligible for re-election as Elected Members until at least one year has elapsed.

Members
G. R. Blakely; J. V. Connolly; E. Percy Edwards; P. H. W. Everitt; B. C. Harrison; E. Levesley; R. N. Marland; Dr. T. U. Matthew.

Associate Member
R. J. C. Whitaker.

By Order of the Council,

W. F. S. WOODFORD,

Secretary.

May, 1960.

* Corporate Members are: Honorary Members, Members, Associate Members.

PARTICULARS OF MEMBERS OF COUNCIL OF THE INSTITUTION 1960-61

This information is given in accordance with Article of Association No. 37. It is compiled from details available up to 21st April, 1960. None of the members shown on this list should be nominated as an Elected Member of Council.

PRINCIPAL OFFICERS

President: G. R. Pryor
Vice-President: H. Burke
Chairman of Council: R. H. S. Turner
Vice-Chairman of Council: A. L. Stuchbery
Immediate Past Chairman of Council: H. W. Bowen, O.B.E.

ELECTED MEMBERS

The following Elected Members will continue in office for a further year from 1st July, 1960:

C. T. Butler	R. S. Clark	N. A. Dudley
B. H. Dyson	J. France	S. G. E. Nash
J. S. Silver	H. Unsworth	G. A. J. Witton

CHAIRMEN OF REGIONAL COMMITTEES ADDITIONAL REPRESENTATIVES ON COUNCIL

At the time of going to press the election of Regional Officers had not been completed.

DIARY FOR 1960

MAY 11 ... ... **Sixth Conference of Engineers Responsible for Standards,** at the Connaught Rooms, London.

JUNE 1 ... ... **The 1959 George Bray Memorial Lecture** (see Journal Supplement).

JUNE 27 ... ... **Summer Meeting,** at the Festival Hall, London, preceded by **The 1960 Viscount Nuffield Paper,** at The Royal Institution, London (see Journal Supplement).

AUGUST 24-28 ... ... **Symposium,** at The College of Aeronautics, Cranfield.
Subject: "Machine Tool Control Systems" (see Supplement).

SEPTEMBER 21 ... ... **The 1960 E. W. Hancock Paper,** in London.

OCTOBER 12-14 ... ... **National Conference,** at Brighton.
Theme: **"Modern Trends in the Manipulation of Metals"**

NOVEMBER 2 ... ... **Annual Dinner,** at the Dorchester Hotel, London.

NOVEMBER 10 ... ... **The 1960 Sir Alfred Herbert Paper,** at The Royal Institution, London.

institution notes

A LETTER FROM THE PRESIDENT

Dear Fellow Member,

You will now be aware from various announcements that the Institution's first Summer Meeting will be held on 27th June, in London. The Conversazione, which forms part of the Summer Meeting, will take place at the Royal Festival Hall.

During my term of office as President, I have had the pleasure of meeting members in all parts of the country at their own Section and Region functions, but this Conversazione will give me and Mrs. Pryor the opportunity of meeting a much larger number of members, their ladies and their guests, than on any other Institution occasion.

Full details of the entertainment arranged — which is quite exceptional — will be found in the Supplement.

I hope you will not miss the opportunity of taking part in what I am sure will be a long-remembered and most enjoyable event.

Yours sincerely,

G. Ronald Pryor.

CALCUTTA SECTION ANNUAL DINNER

The Annual Dinner of the Calcutta Section was held on 6th February, 1960, at the Great Eastern Hotel, Calcutta. The Dinner, at which the principal guest was the Secretary of the Institution, Mr. W. F. S. Woodford, was attended by 128 members and friends, and was preceded by a cocktail party, where Mr. Woodford was given the opportunity of meeting many members.

Amongst the guests was Mr. R. M. Currie, C.B.E., M.I.Prod.E., Head of the Work Study Department of I.C.I. Ltd., and who, like Mr. Woodford, was on a visit to India.

Three of the guests — Mr. Woodford, Mr. Currie and Mr. Satow — with the Calcutta Section Committee. (Left to right): Mr. S. R. Chatterjee; Mr. S. J. Shahany; Mr. P. J. O'Leary (Honorary Secretary); Mr. Currie; Mr. Satow; Mr. T. R. Gupta (Section Chairman); Mr. Woodford; Mr. E. W. H. Scaife; Mr. P. Bhattacharji; Mr. B. F. Goodchild; and Mr. H. N. Ghosal.

PRESENTATION TO BIRMINGHAM MEMBER

Mr. J. H. Hughes

The Annual Dinner - Dance of the Birmingham Section, held on 13th February, 1960, was made the occasion of a presentation to **Mr. J. H. Hughes,** M.B.E., long-time member of the Institution, and until recently a member of the Birmingham Section Committee.

The presentation took the form of a cut glass vase, and in recognition of his long years of service to the Institution, the Birmingham Section arranged for him to be made a Life Member.

Awarded the M.B.E. in 1945 after nine years' service devoted to building up aero-engine production. Mr. Hughes continued his activities as Works Superintendent at The Rover Company's Agency Factory at Acocks Green until his retirement at the end of 1958, having completed 34 years with the Company.

MIDLANDS REGION MEETING

The 1960 Midlands Regional Paper, presented at The Sibree Hall, Coventry, on 7th April, attracted an audience of approximately 250 to a most successful meeting.

The speaker was Mr. W. Allen, B.Arch., A.R.I.B.A., Superintending Architect of The Building Research Station, D.S.I.R., Watford, and his subject was "Factory Design for the Future".

The Paper will be published in the June issue of *The Production Engineer.*

ROCHESTER CHAIRMAN PRESENTS CERTIFICATES

Mr. Peter Bradford, Chairman of the Rochester Section of the Institution, recently presented Higher National Certificates for Production Engineering to five students of the Medway College of Technology. The successful candidates were J. Kidd (Chatham Dockyard); J. P. Roche (Elliott Bros., Rochester); D. Robinson (Elliott Bros., Rochester); and B. R. Lawrence and M. V. Excell (two apprentices from Tilling-Stevens, Maidstone).

Medway College is the first college in Kent to run a H.N.C. course in Production Engineering, and these were the first awards to be made since the course was started, two years ago.

Below: Mr. Bradford with the five successful students.

Courtesy of *Chatham Standard*

NEWS OF MEMBERS

Mr. E. W. Hancock, O.B.E., Honorary Member, and Past President of the Institution, has been appointed Chairman of the Coventry and District Disablement Advisory Committee. He has also recently been elected to the Committee of Human Sciences of the Department of Scientific and Industrial Research. Mr. Hancock is Director of Special Projects, Humber Ltd.

Mr. J. R. Bergne-Coupland, Member, who is Assistant Managing Director of Ruston & Hornsby Ltd., has been appointed High Sheriff of Lincolnshire. Mr. Bergne-Coupland has been a member of the Lincoln Section Committee since its formation in 1943, and was Chairman of the Section from 1948 to 1950.

Dr. G. S. Brosan, Member, formerly Lecturer in Mechanical Engineering at Willesden Technical College, is now Senior Assistant Education Officer to the Education Committee of the County Council of Middlesex. Dr. Brosan serves on the Papers Committee of the Institution.

Mr. R. N. Cook, Member, formerly Research and Development Manager of the Wimet Division of Wickman Ltd., has now been appointed Assistant General Manager of that Division.

Mr. W. S. Hollis, Member, Assistant Director, Aircraft Production Development, Ministry of Aviation, has been awarded a Doctorate of Philosophy of the University of London.

Mr. R. Parish, Member, has been promoted from Senior Executive to Director of the Benjamin Crook & Sons Ltd. Group of Companies.

Mr. Leonard Walker, Member, Director of Noble & Lund Ltd., Gateshead, has been appointed General Manager. Mr. Walker is a past Chairman of the Newcastle upon Tyne Section of the Institution.

Mr. F. Woodifield, Member, has retired from business. Mr. Woodifield, who was Assistant Managing Director of the Park Gate Iron and Steel Co. Ltd., Rotherham, has been actively concerned with the work of the Institution for many years and all members will wish him a long and happy retirement. A longstanding member of the Sheffield Section Committee, of which he is a Past Chairman, he is also a Past Chairman of the Institution's Membership Committee and has served on the Education Committee.

Mr. J. P. Dainty, Associate Member, has relinquished his position as Production Development Engineer at Vickers-Armstrongs (Aircraft) Ltd., Weybridge, and has taken up an appointment as Engineer II responsible for Machine Tool Development, at the Atomic Weapons Research Establishment, Aldermaston, Berkshire.

Mr. B. N. Ganguly, Associate Member, has relinquished his position as Methods Engineer with Machinery Manufacturers Corporation Limited, Kidderpore, Calcutta, and has taken up an appointment as Production Engineer with Messrs. Saxby & Farmer (Ind.) Private Ltd., Calcutta.

Mr. C. T. John, Associate Member, has taken up an appointment as Senior Technical Editor at the Culcheth Laboratories, Research and Development Branch, Development and Engineering Group, U.K.A.E.A., Culcheth, Warrington.

Mr. G. D. Kendrick, Associate Member, is now Lecturer in the Department of Production Engineering and Management at the Wolverhampton and Staffordshire College of Technology.

Mr. H. J. Manners, Associate Member, is now Section Leader at Vickers-Armstrongs Ltd., South Marston, Swindon, in the nuclear design office.

Mr. R. A. Powell, Associate Member, has recently joined Harold Whitehead and Partners Ltd. as Production Engineer Consultant. He was previously with H. H. Fraser and Associates (Rhod.) (Pvt.) Ltd.

Mr. G. M. Ranson, Associate Member, formerly General Works Manager of Audley Engineering Co. Ltd., Newport, has been appointed Works Director. Mr. Ranson is a member of the Institution's Materials Handling Group Committee.

Mr. Gordon D. Robson, Associate Member, has been appointed a Director of Noble & Lund Ltd., Gateshead. Mr. Robson is a past Chairman of the Newcastle upon Tyne Graduate Section of the Institution.

Mr. D. J. Taysom, Associate Member, has now returned from a period abroad and has taken up the appointment of Managing Director of The Brush Crystal Co. Ltd., Hythe, Southampton.

Mr. B. E. Terry, Associate Member, is now Technical Manager and Chief Engineer of Lacrinoid Products Ltd., Gidea Park, Essex.

Mr. J. R. Thompson, Associate Member, has taken up an appointment with the Churchill Machine Tool Co. Ltd., Broadheath, near Manchester, as Technical Representative in the Midlands area.

Mr. W. C. Tuck, Associate Member, has been transferred to the Liverpool Factory of Otis Elevator Co. Ltd., as Assistant Works Superintendent.

Mr. G. Webb, Associate Member, is now Assistant Factory Manager (with special reference to technical problems of production) at the Latex plant of Playtex Ltd., Port Glasgow, Renfrewshire.

Mr. H. J. C. Weighell, Associate Member, formerly Production Superintendent, Industrial Systems, Sperry Gyroscope Co. Ltd., is now Chief Planning Engineer, Group Production, with the Rootes Group, Coventry. Mr. Weighell serves on the Papers Committee of the Institution.

Mr. M. T. Brown, Graduate, is now Commissioned in the Education Branch of the Royal Air Force.

Mr. Alan Green, Graduate, has relinquished his position as Production Management Advisor to the British Institute of Management, and is now Industrial Engineer with Mullard Equipment Ltd.

Mr. D. W. G. Hall, Graduate, has left Guest, Keen & Nettlefolds (Midlands) Ltd. to take up the appointment of Assistant Works Manager at Motor Components (Birmingham) Ltd., Bilston, Staffordshire.

Mr. R. Laxon, Graduate, has left Baker Perkins Ltd. to join Unilever Ltd., Food Research Department, Sharnbrook, Bedfordshire, as a Project Engineer.

Mr. P. W. Millyard, Graduate, has relinquished his position with the English Electric Co. Ltd., and has taken up an appointment as a Design Engineer Grade III with the Australian Weapons Research Establishment.

Mr. D. W. Minett, Graduate, has relinquished his position as Work Study Engineer with Osram (G.E.C.) Lampworks and is now Development Engineer with Mallory Metallurgical Products Ltd., Wembley, a subsidiary of Johnson, Matthey & Co. Ltd.

Mr. A. K. Mitra, Graduate, has relinquished his position of Graduate Mechanical Engineer with C. A. Parsons & Co. Ltd., Newcastle-upon-Tyne and has now joined Imperial Chemical Industries (India) Private Ltd., Calcutta, on his return to India.

Mr. H. E. Alan Noble, Graduate, has been appointed a Director of Noble Lund Ltd., Gateshead, and takes over the duties of Works Manager. Mr. Noble is a past Chairman of the Newcastle upon Tyne Graduate Section of the Institution.

Mr. M. J. Paine, Graduate, formerly Project Engineer with C.V.A. Jigs, Moulds & Tools Ltd., Brighton, has been appointed Assistant Mechanical Engineer to Messrs. W. R. Sykes Interlocking Signal Co. Ltd.

Mr. R. Rainford, Graduate, has relinquished his position as a Work Study Engineer with the General Electric Co. Ltd., and has taken up an appointment as a Purchasing Technical Assistant with Brown and Polson Ltd., Manchester.

Mr. E. Rath, Graduate, has recently been appointed Quality Controller of the Palestine Can Co. Ltd., of Petach-Tikvah, Israel, an associate Company of The Metal Box Co. (Overseas) Ltd., England.

Mr. R. Sutcliffe, Graduate, formerly with Denford Small Tools (Brighouse) Ltd., has been appointed Northern Editorial Representative for "Machinery".

Mr. J. M. Webb, Graduate, has now taken up an appointment in the Engineering Department on design and layout of plant, with Plant Protection Ltd., Yalding, Kent, a subsidiary of I.C.I. Ltd.

BINDERS FOR "THE PRODUCTION ENGINEER"

As a result of requests from members, the Institution is now able to supply the "Easibind" type of binder, in which metal rods and wires hold the issues in place, and which is designed to hold six issues.

It will be found that copies of "The Production Engineer" can be quickly and simply inserted into this binder, without damage to the pages, and that binding six issues at a time, instead of twelve, will facilitate easier reference and handling of the volumes.

The new binders may be obtained from: The Publications Department, 10 Chesterfield Street, Mayfair, London, W.1, price 10/6 each, including postage. Date transfers, for application to the spine of the binder, can be supplied if required, price 6d. each.

Hazleton Memorial Library

ADDITIONS

Members are reminded of the following Library rule, which is frequently ignored:

"The initial loan period is one month, and borrowers may keep books and periodicals for further periods of one month, if they ask the Librarian, and if no other borrower wants them. Applications for renewal may be made by post or telephone."

Parsons, S. A. J. **"Production Tooling Equipment: The Design of Jigs, Tools and Gauges."** (2nd edition.) *London, Cleaver-Hume Press,* 1960. 328 *pages. Diagrams. Tables.* 28s.
This is the second edition of a textbook recommended by The Institution of Production Engineers for Part II of the Associate Membership Examination. It is based on lectures delivered at The College of Advanced Technology, Birmingham, at which the author was formerly in charge of Production Engineering. In this edition the author has revised the sections on ceramic tools and workshop and inspection gauges, and has added something on "throw-away" tool tips and on automation. The first two parts of the book deal with the design of drilling jigs and fixtures, in which as far as possible each jig or fixture is discussed relative to the component with which it is to be used, and with a diagram. The third part deals with cutting tools and tool layouts for various machines, with special attention paid to the design and application of cutting tools. There are sections on micro-drilling, the design of high-rake milling cutters, broach design, with special reference to surface broaching; and a comprehensive tooling layout for a sliding head automatic. The last part is concerned with the design of practical gauges. The six appendices comprise: Notes on jig and tool design as an academic study — typical syllabus for a course in jig and tool design for H.N.C. Production Engineering (one session) — Typical syllabuses for a course in jig and tool design for the H.N.C. in Production Engineering (two sessions) — Tool design: Syllabus for the Associate Membership examination of The Institution of Production Engineers — Selected British Standards — Jig and tool design: Typical examination questions.

Roberts, John A. (compiler). **"Spring Design and Calculations."** (9th edition.) *Redditch, Herbert Terry and Sons Ltd., Technical Research Laboratory,* 1958. 135 *pages. Diagrams. Tables.*
Contents: Helical compression and extension springs — Extension springs and initial tension — Calculation of helical compression and extension springs — Square and rectangular section springs — Volute springs — Conical springs — Valve springs — Surging of valve springs — Natural frequency — Natural frequency of a single mass system — Springs with material subject to bending stresses (helical and spiral torsion of springs) — Power of clock-type springs — Flat springs — Multiple leaf springs or laminated springs — Belleville washers — Waved washers — Circlips or retaining rings — Combined axial and horizontal loading on compression of springs — Spring driving belts — Velocity of helical springs — Helpful hints when ordering springs — Tables — Useful data — Spring materials.

Rudner, Merritt Allen. **"Fluorocarbons."** *New York, Reinhold Publishing Corporation; London, Chapman and Hall,* 1958. 238 *pages. Illustrated. Diagrams. Tables.* 46s. (Reinhold's Plastics Application Series.)
Deals with the properties and chemistry of fluorocarbon plastics; and with processing and fabrication techniques. Compares the capabilities of fluorocarbons with those of other plastics, and describes their chemical, electrical and mechanical applications.
Contents: Fluorocarbon resins — General properties of the fluorocarbons — Chemistry of the fluorocarbons — Processing techniques for polytetrafluoroethylene — Processing techniques for polytrafluoroethylene — Effects of fabrication on the properties of teflon — Electrical applications — Mechanical applications — Future of the fluorocarbons — Bibliography.

Schaller, Gilbert E. **"Engineering Manufacturing Methods."** (2nd edition.) *New York, London, etc., McGraw-Hill,* 1959. 682 *pages. Illustrated. Charts.*
This book describes most engineering manufacturing processes, and incorporates information about recently developed processes. Preliminary chapters summarise the properties of engineering materials, and are followed by chapters on casting and moulding processes; heat treatment; machine shop processes; metrology; and welding and brazing. There are chapters on numerical control of machines; and on transfer machining. "Survey questions" at the end of each chapter enable the student to test his knowledge of the subject dealt with.

Smith, W. Mayo. **"Vinyl Resins."** *New York, Reinhold Publishing Corporation; London, Chapman and Hall,* 1958. 282 *pages. Illustrated. Diagrams.* 46s. (Reinhold's Plastics Application Series.)
Surveys the manufacture, chemistry, types and properties of vinyl resin. New polyvinyl "pearls" and Delrin resins are included. Typical applications of vinyls are given in great detail, and such items as vinyl laminates, rigids, foamed material and latex paints are stressed.
Contents: Scope of the vinyls — Types and properties — Chemistry — Manufacture and fabrication — Applications — New developments.

Thompson, M. Stafford. **"Gum Plastics."** *New York, Reinhold Publishing Corporation; London, Chapman and Hall,* 1958. 189 *pages. Diagrams.* 36s. (Reinhold's Plastics Application Series.)
The general properties, chemistry and practical application of rubber-modified or gum plastics resins are dealt with. The work centres round the impact rigid polystyrene polymers, ABS polymers and impact-rigid polyvinyl chloride polymers as the more important commercial compounds. Contents: Introduction — Basic chemistry and manufacture — Processing and fabrication — Application of gum plastics.

Von Neumann, John. **"The Computer and the Brain."** *New Haven, Conn., Yale University Press,* 24s.
This book is based on material prepared for the Silliman lecture which the author was invited to present to Yale University, but was unable to deliver before his death in 1957. The author was one of the foremost mathematicians of the 20th century. In his book he studies the analogy between the human brain and nervous system, and modern calculating machines.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L. P. Coombes .... *Oxford*
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Midlands	A. C. Turner
North Midlands	J. Cox
Northern	T. Young
North Western	J. P. Speakman
Northern Ireland	J. G. Easterbrook
Scotland	J. Nicolson Low
South Eastern	J. Aikman
Southern	W. F. Reid
South Western	A. Eustace
Wales	A. E. Haynes

SECTION HONORARY SECRETARIES

AUSTRALIA

Adelaide (South Australia) ...	B. H. M. Coombes, 11 Elmo Avenue, Westbourne Park, Adelaide, Australia.
Melbourne (Victoria, Australia)	A. G. Jones, 13 Laburnum Street, Middle Brighton, Victoria, Australia.
Melbourne Graduate (Victoria Australia)	E. P. H. James, 455 Stephenson Road, Mount Waverley, Melbourne, Victoria, Australia.
Sydney (New South Wales)	K. G. Slorach, 98 Church Street, Castle Hill, New South Wales, Australia.

CANADA

Canada	A. M. Hand, 18 Rintella Court, Scarborough, Ontario, Canada.

INDIA

Bombay	R. D. Mistry, "Churchgate House", 32 Veer Nariman Road, Bombay, India.
Calcutta	P. J. O'Leary, c/o Guest, Keen, Williams Ltd., 41 Chowringhee Road, Calcutta, India

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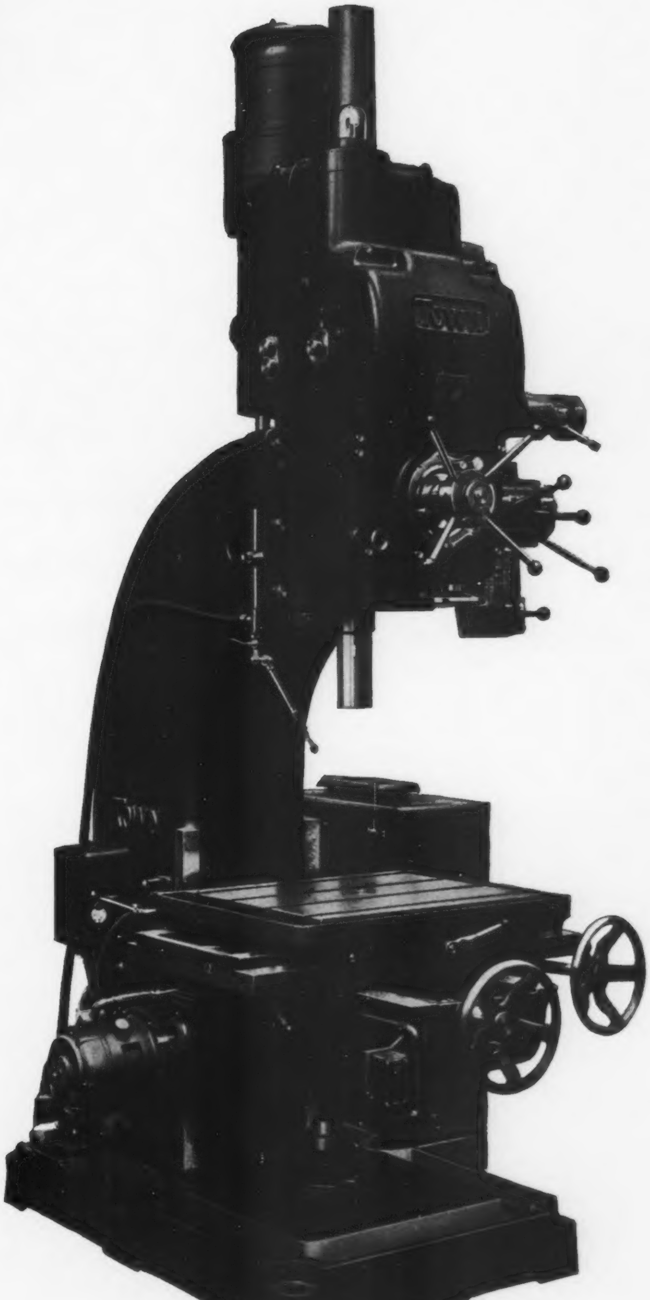

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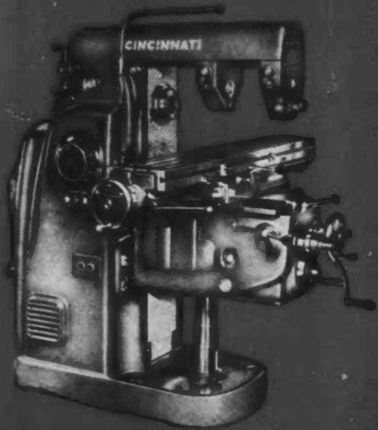

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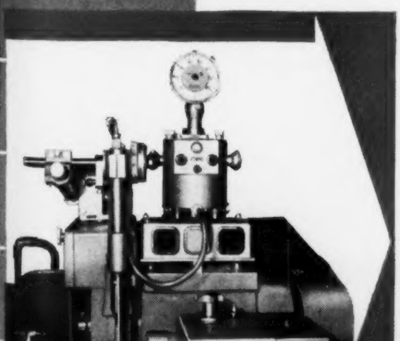
(B) For completely automatic control of component size and machine operating cycle.

Moderately priced OMT-ETAMIC control systems are applicable to all types of grinding machines, lathes, transfer machines, cold rolling mills, extruding machines, etc.



A typical OMT-ETAMIC grinding machine application. Final wheelhead infeed, finish diameter of spline shaft and wheelhead retraction are all controlled by the Automation Head.

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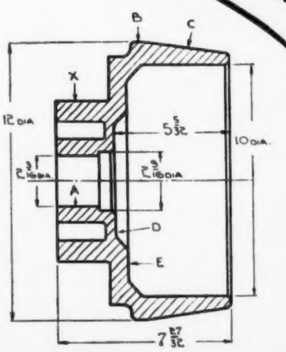

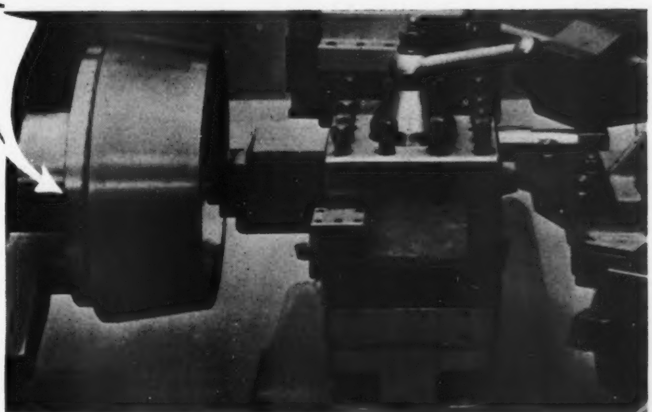

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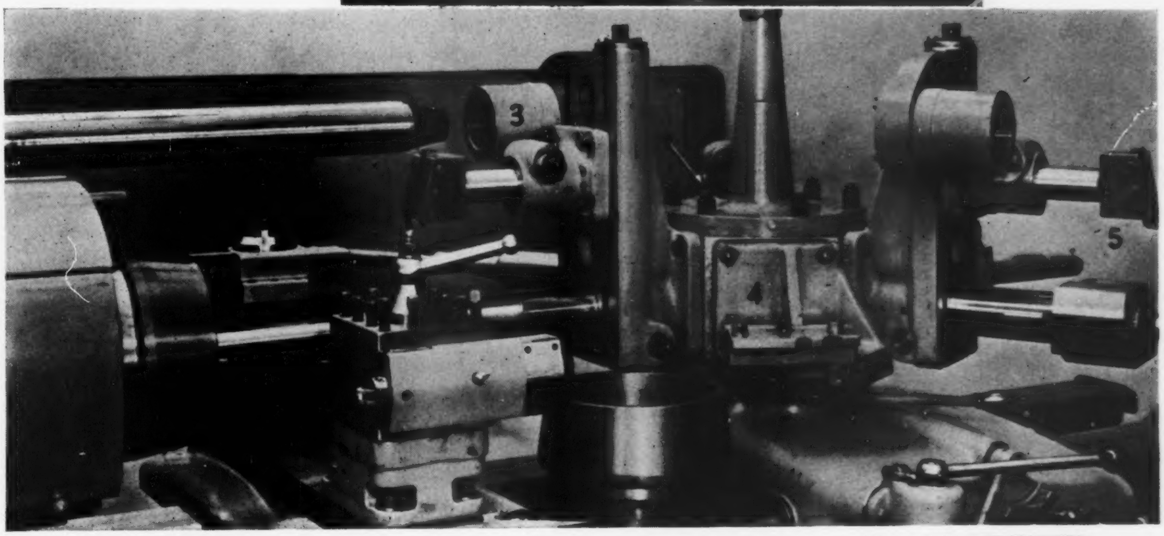
Tungsten Carbide Cutting Tools



DESCRIPTION OF OPERATION	Tool Position: Hex. Turret	Tool Position: Cross-slide	Spindle Speed R.P.M.	Surface Speed Ft. per Min.	Feed Cuts per inch
1. Chuck on X (using Loading Attachment)	1	—	—	—	Hand
2. Rough Bore A & $2\frac{9}{16}$" dia. and Chamfer	2	—	375	260	64
3. Face (2 Cuts)	—	Front 1	93	278	64
4. Rough Bore 10" dia. Rough Knee Turn B and Rough Taper Turn C	— 3	— Rear	75	240	44
5. Contour Face D & E (Rough & Finish)	4	Front 3	93/125	242/325	64
6. Finish Bore 10" Finish Knee Turn B and Finish Taper Turn C and Chamfer 10" dia.	— 5	— Rear	125	390	64
7. Chamfer Outside Dias.	—	Front 2	125	390	Hand
8. Finish Microbore $2\frac{9}{16}$" dia.	6	—	580	333	88
9. Remove (using Attachment)	1	—	—	—	Hand

Ward

No. 10 TURRET LATHE

FITTED WITH 18in TUDOR 3-JAW CHUCK

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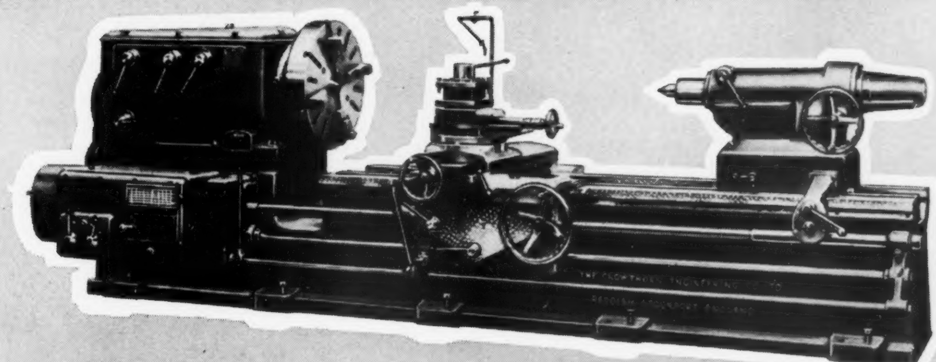
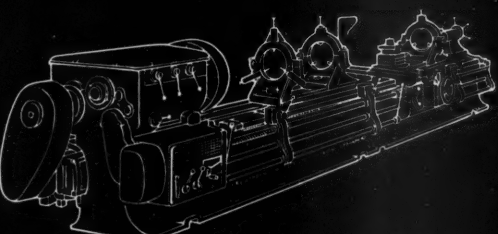
Ward Lathes will be demonstrated on Stand 205, Empire Hall, Olympia, June 25 to July 8.



Crowthorn 18 in. Centre Lathe on 15 ft. 3 in. gap bed, admitting 8 ft. 0 in. between centres. Swing over bed 36¾ in. Swing in gap 57 in. × 21 in., hole through spindle 4¼ in. dia. 25 h.p. motor drive.



Crowthorn 15 in. Centre Lathe on 31 ft. 0 in. gap bed.

Crowthorn long bed heavy duty Lathes can be supplied with any length of bed to suit customers' requirements. A full range of fittings and attachments is available.

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HEAVY DUTY LATHES

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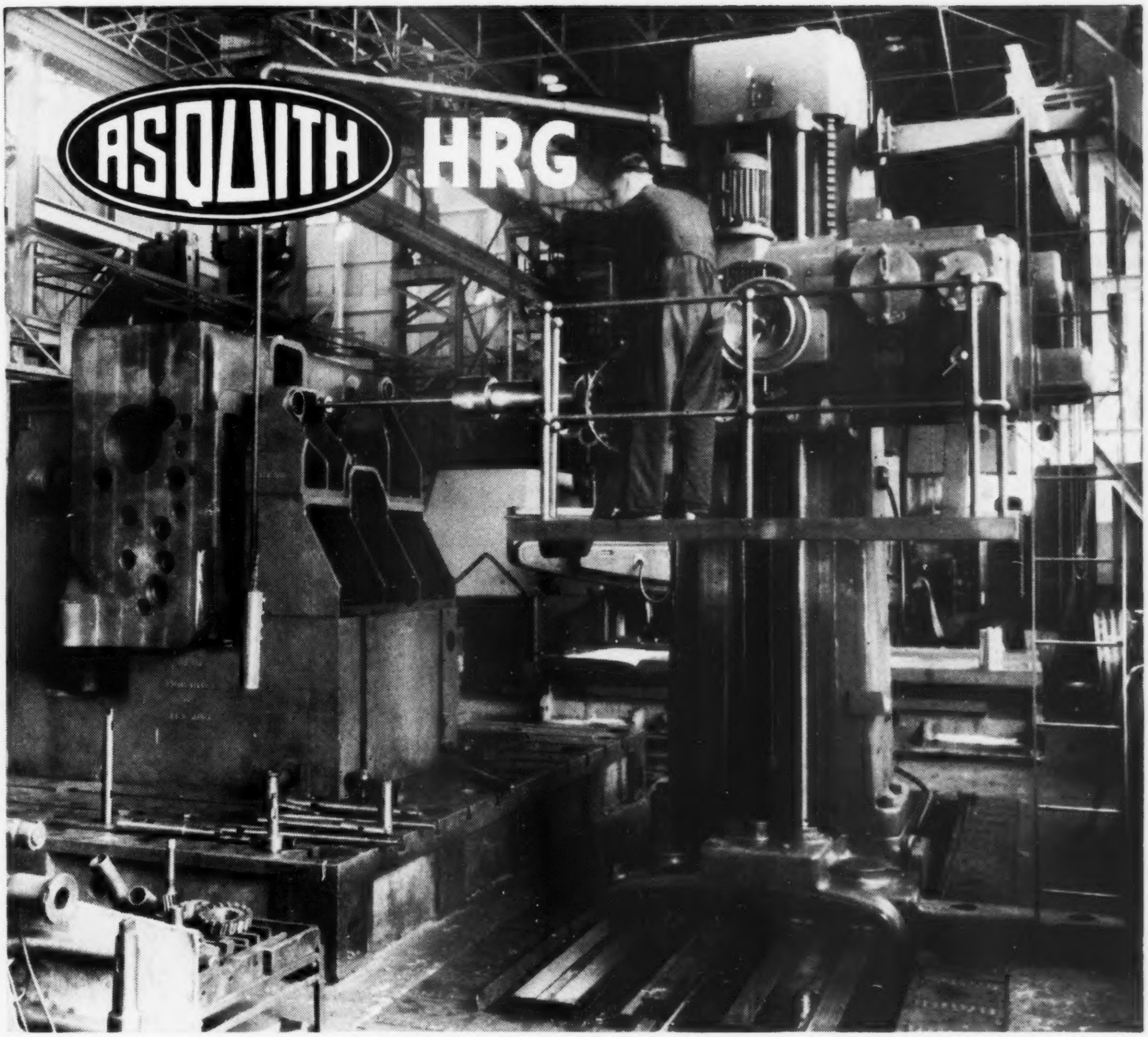
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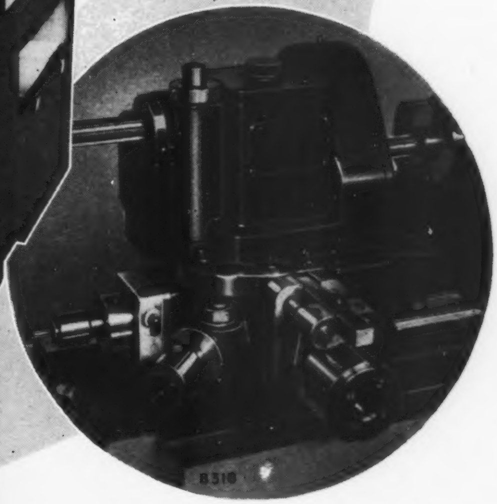
BROWN and WARD type 575

Single Spindle Automatic Bar Machine

Max. spindle capacity — $\frac{3}{4}$" or $\frac{7}{8}$" dia.
24 cycle times — 2·5 to 164 secs.
10 spindle speeds — 470 to 4,350 r.p.m.



3-position turret with two revolving and one fixed station for high-speed drilling, differential threading or over-running top withdrawal.

This machine retains many well-known Brown & Ward features, but also incorporates several new innovations, including the two illustrated. Also equipped with built-in accelerator mechanism to reduce stock feeding time; a redesigned vertical slide with longitudinal and vertical micrometer adjustment.

Independently controlled turret withdrawal cams, together with a unique arrangement for indexing, reduce turret idle time to a minimum.

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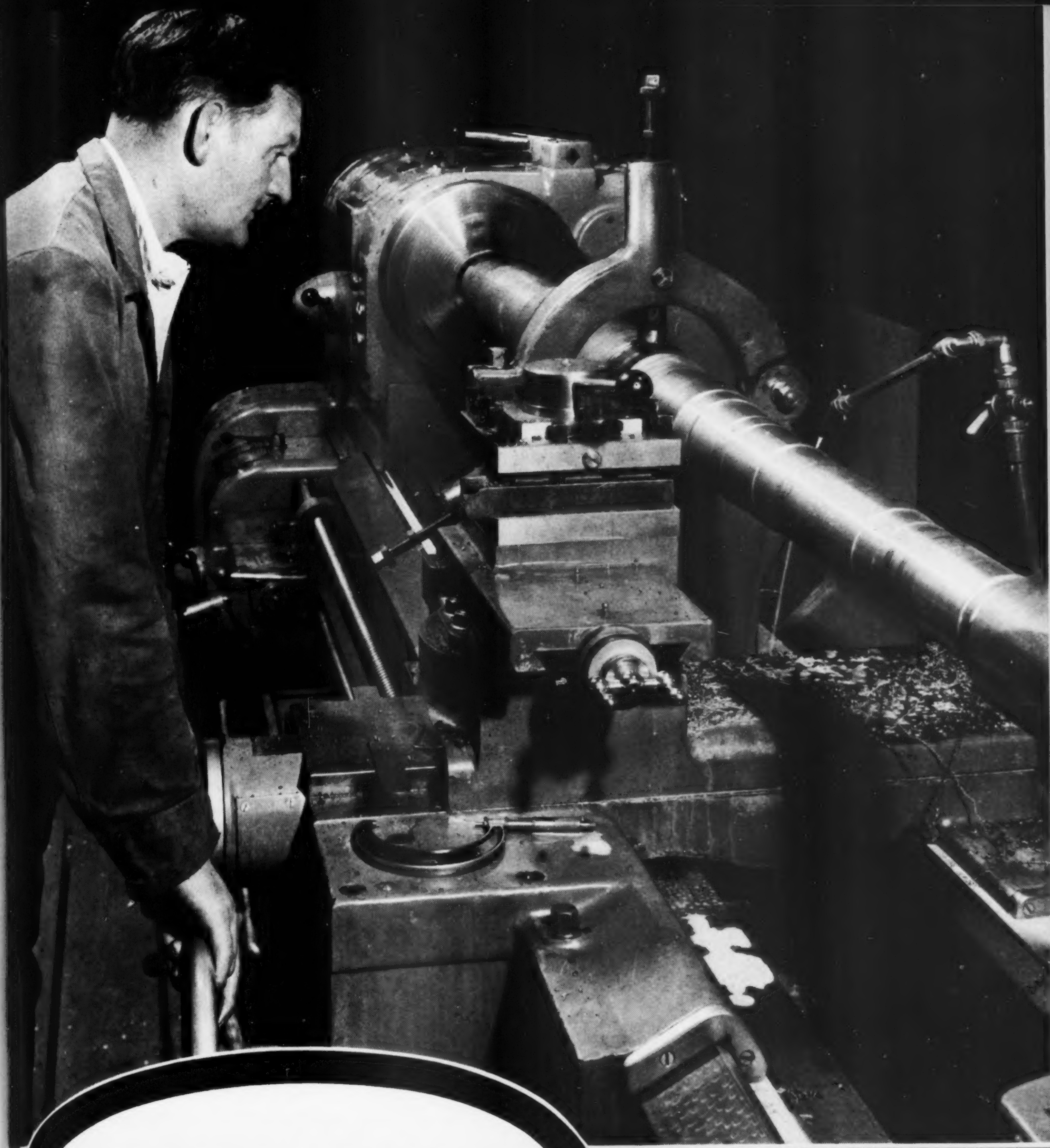

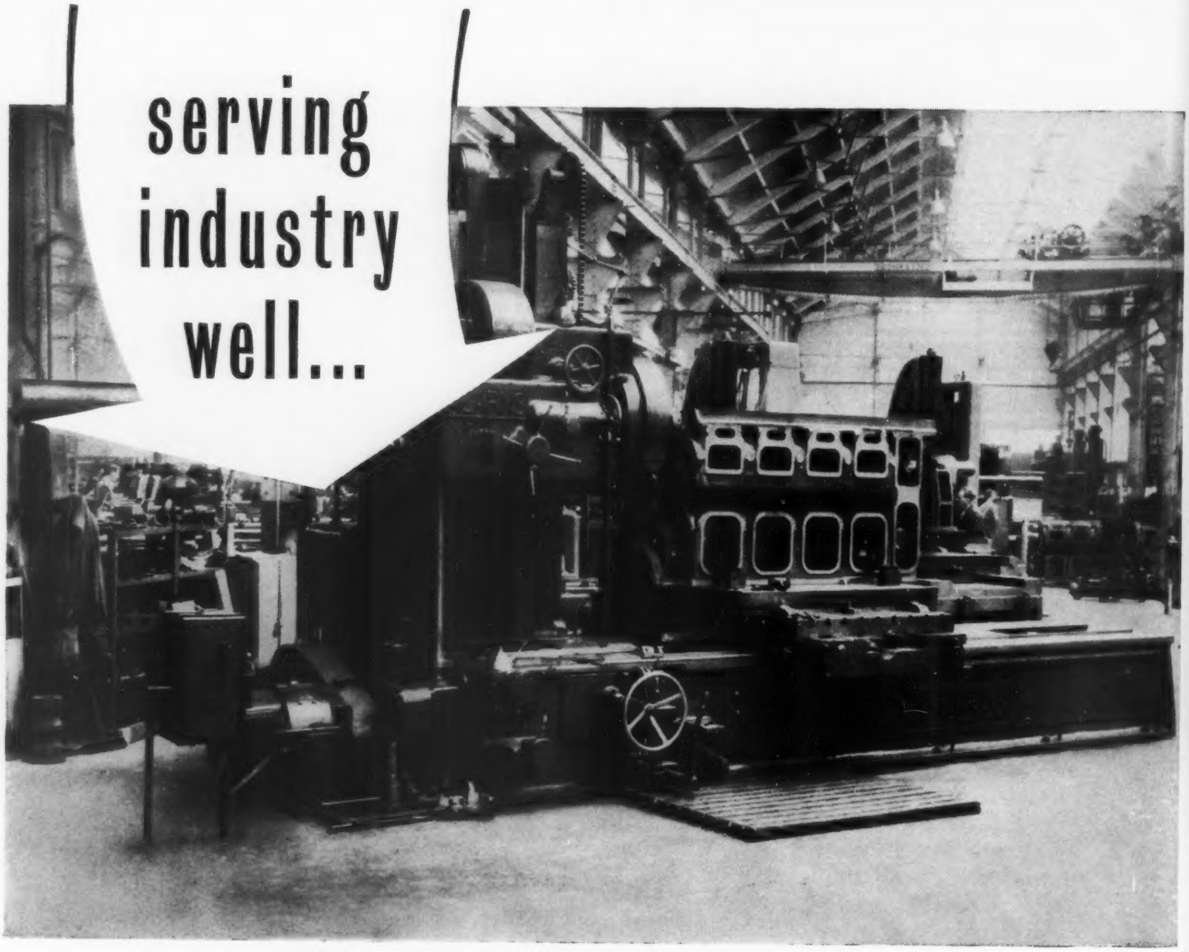

No. 5 Kearns Patent Machine machining an oil engine crankcase casting at the works of The Vulcan Foundry Limited.

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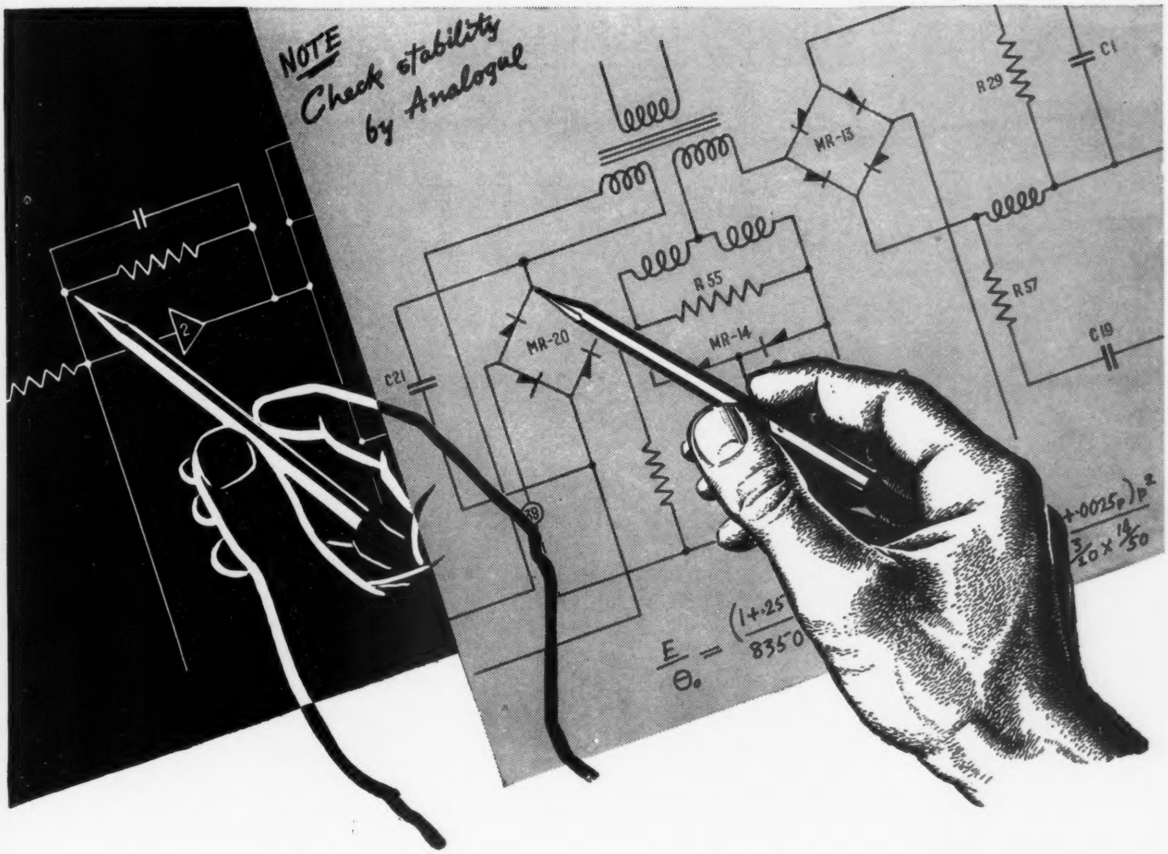

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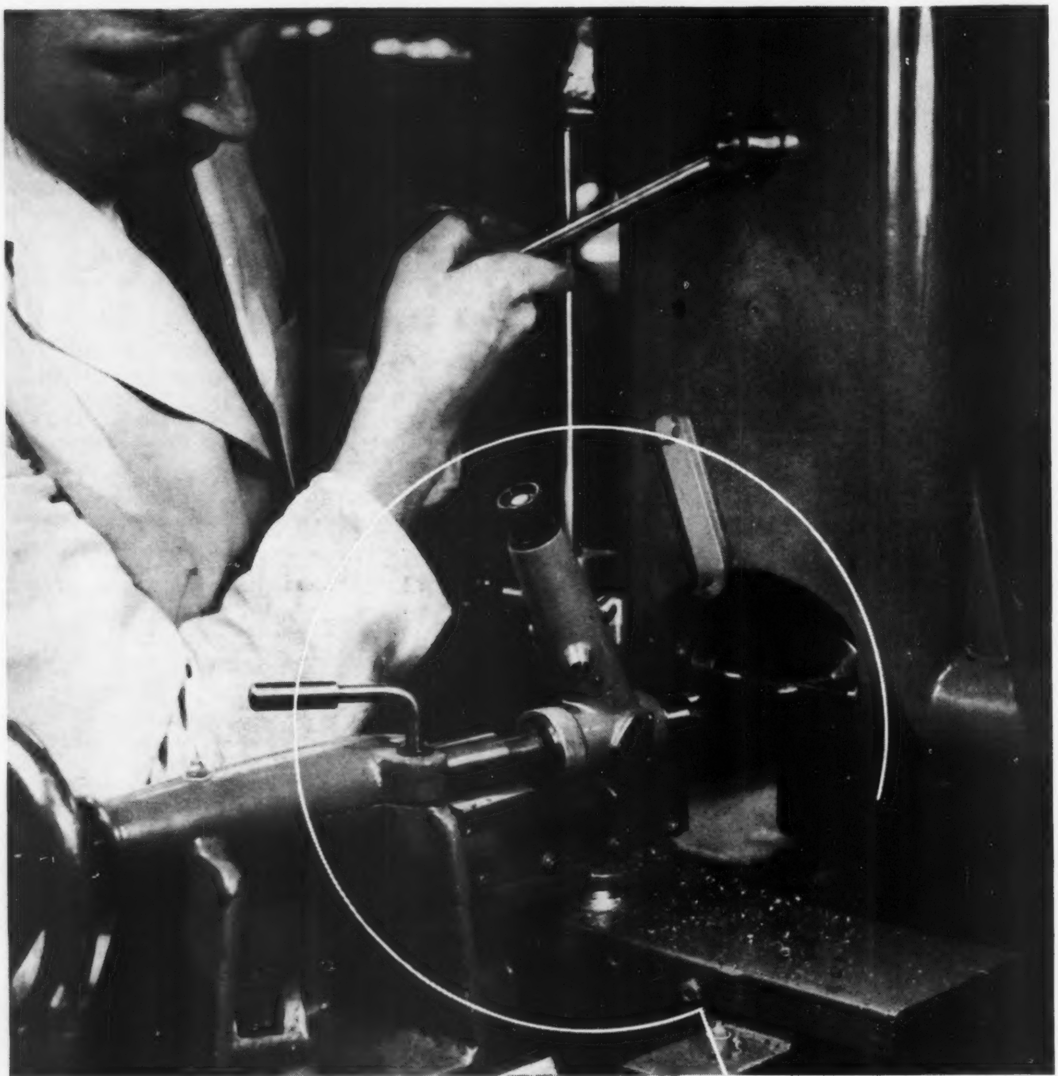

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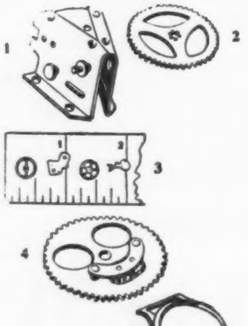

1 Three hollow rivets and single ball end rivet fastened. Single Operation.

2 Wheel stabbed to form keys. Single Operation.

3 Crop form after Auto turning. Pierce holes and form Location Studs. Pierce centre hole. Pierce two smaller holes and crop form at small end.

4 Hollow rivets on saddle fastened. Single Operation.

5 Forming on Strap-holders.

	H.3	H.5
Capacity	1 ton	2 ton
Throat to centre of Ram	$2\frac{1}{2}$"	$3\frac{1}{2}$"
Maximum daylight	$3\frac{1}{4}$"	$5\frac{3}{8}$"
Stroke	$1\frac{13}{16}$"	$2\frac{5}{16}$"

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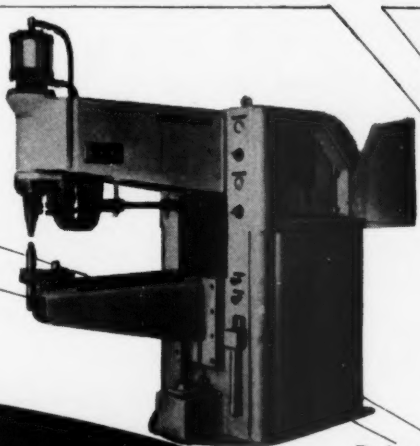
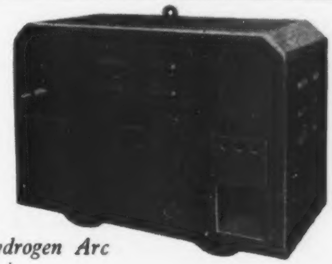


Resistance



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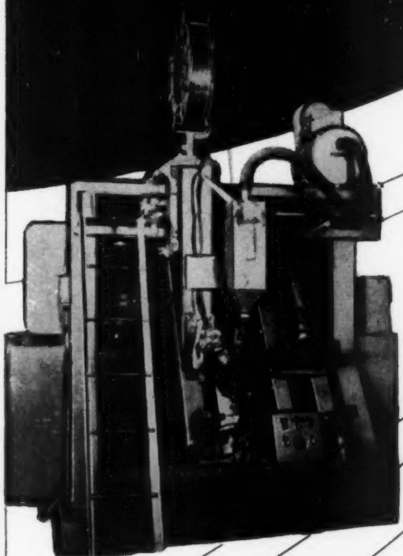

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Electrical Aids in Industry *Data Sheet* **No. 11**

Dielectric Heating - 2

The ability of dielectric heating to generate heat through the mass of a suitable material provides the following considerable advantages over other heating methods.

1 A body of uniform section and composition is raised in temperature uniformly throughout. Hence there is no waiting for heat to be transferred from an external heat source to the surface of the body and thence to its interior, and this is of particular advantage when the body is thick, and, as is often the case with dielectric materials, has poor heat-conducting properties.

2 The rate of heating of such bodies is, therefore, much faster than by external heating methods.

3 Since there is no external heat source, overheating or burning of the surface of a heat-sensitive material is avoided.

4 High thermal efficiency is achieved.

5 The amount of heat generated in the work is usually predictable and power input and heating time can be under positive control.

6 Production can start immediately after switching on and no current is used, nor heat lost, during periods of shut-down.

7 Vastly increased productivity is obtainable with less labour (usually unskilled), and fewer machines and less floor space are required.

8 Flexibility of layout makes it possible to plan the factory to best advantage, as dielectric heating equipment can usually be inserted directly into the production line.

Dielectric heating: typical application data

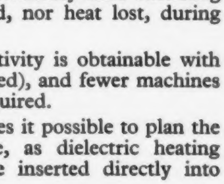
Typical application	Frequency	Radio frequency power
Thermoplastic welding.	20-100 Mc.p.s.	Up to 1 kW
Plastic pre-heating, wood glueing.	10-40 Mc.p.s.	2–30 kW
Plywood manufacture.	2-10 Mc.p.s.	Above 30 kW

Note: 1 Mc.p.s. = 1,000,000 cycles per second.

A few of the industrial applications of dielectric heating are briefly described below.

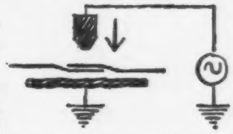
Preheating Thermosetting Plastics

Dielectric heating is the ideal way of preheating moulding powder pellets used in the production of thermosetting plastic mouldings, since these materials are generally poor heat conductors. Properly applied, dielectric preheating promotes faster curing and hence a shorter moulding time, often increasing production ten to fifteen times. There is a marked reduction in tool wear, and thicker sections can be moulded, as the material is plastic when placed in the mould. There is less damage to, and movement of, metal inserts.

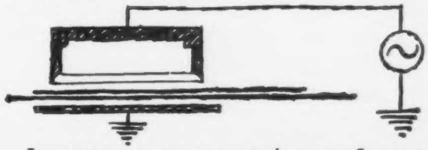


Welding of Thermoplastic Materials

An important and extensive application of dielectric heating in the plastic industry is the welding of thermoplastic sheets in the fabrication of such commonly used articles as raincoats, hoods, handbags, pouches and packaging materials. Dielectric heating is the only method which can usefully be employed since the heating electrodes, and hence the outside sheet surfaces remain cool while the inside surfaces forming the joint are fused, and a perfect weld results.



Two or more thermoplastic sheets are welded under pressure from electrodes suitably shaped to the area of weld required, the current being switched on at the same time as pressure is applied, and off as soon as the weld is completed and the pressure released. Stitching is thus eliminated and a far stronger joint achieved.



In most cases, component pieces are first cut from patterns and preliminary welding carried out to attach any fastening tabs and the like. The pieces are then brought together in a suitable loading frame and the main welding carried out to produce the complete article. In some cases, a suitably profiled electrode can be fitted with a knife edge to cut the sheets immediately outside the weld line, welding and pattern cutting being thereby carried out in the one operation. Dielectric welding can be applied also to very large thermoplastic products such as linings for swimming pools, and cinema screens.

Drying

Drying of materials by dielectric heating has the great advantage that the material tends to dry out from the centre, the reverse of what happens when external heating methods are employed, and the risk of overdrying and overheating of the surface is eliminated. In general ½ to 1 unit of electricity is required to drive off 1 lb. of moisture, depending upon the thermal properties of the material being dried. While the removal of large amounts of water from inexpensive commodities may sometimes be uneconomical, dielectric heating in the production line often leads to a higher overall production efficiency. It is valuable for removing final moisture traces and becomes increasingly economical as the value or heat-sensitivity of the commodity increases.

Rubber

External heating tends to dry and cure the surfaces of a thick latex mass before its centre, but dielectric heating properly applied promotes uniform conditions throughout.

Loaded rubber may not heat uniformly in a dielectric field due to uneven dispersion of its load, but nevertheless rubber preforms loaded up to about 15% are preheated dielectrically to reduce moulding times appreciably, the temperature evening out in the mould to give uniform curing.

Further examples are given in Data Sheet No. 12.

For further information get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available — "Induction and Dielectric Heating" is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

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Compact design reduces to a minimum, distance from drill head to machine spindle, whilst careful selection of material ensures an extremely efficient light weight head.

Heads are available with any number of spindles, covering a wide range of sizes

MAXIMUM PRODUCTION ON DRILLING, REAMING, TAPPING AND SPOT FACING OPERATIONS

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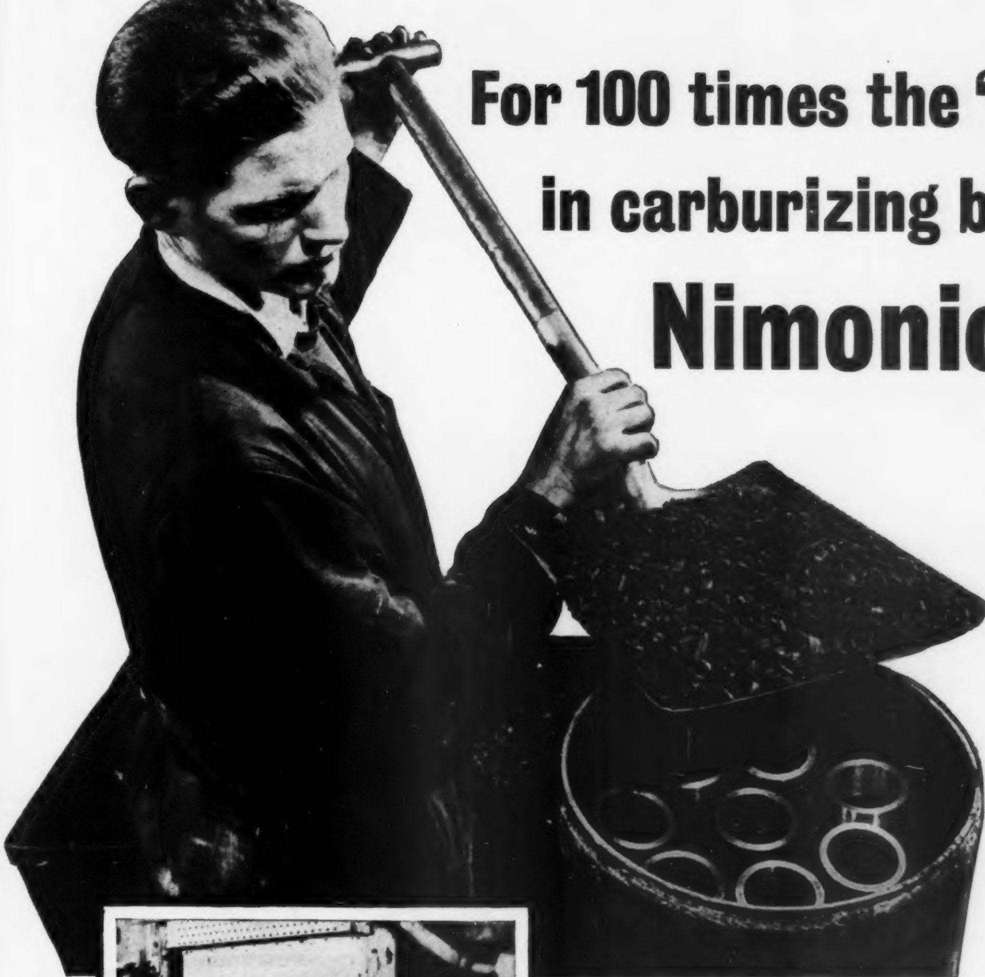
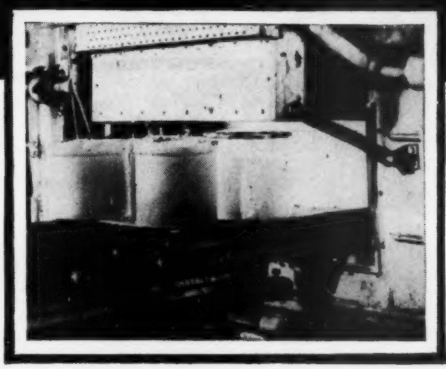
COVENTRY 'PHONE: COVENTRY 88641

We also manufacture Rotary Cam and Profile Milling Machines, Short Thread Milling Machines, Gear Tooth Rounding Machines, Tapping Machines, End Facing and Centring Machines, Special Machine Tools for High Production.

For 100 times the 'life' in carburizing boxes

Nimonic* 75





David Brown Industries Limited have found that carburizing boxes of Nimonic 75 heat-resisting alloy outlast mild steel no less than 100 times. The boxes are still in good condition after 8,000 hours of service without repair. Carburizing temperatures range from 900° to 915°C, and treatment time is approximately 18 hours. This nickel-chromium-alloy has also far outlasted all other materials used.

Nimonic 75 is easily shaped and welded. Because of its strength at elevated temperatures, thinner sections can be used, permitting greater loads, less furnace time, easier handling and a longe service life.

TOP

Charging a carburizing box made from wrought Nimonic 75 alloy. In the 'pack carburizing' of a wide variety of gears, David Brown Industries use this material increasingly for its ease of fabrication, resistance to heat and superior 'life'.

INSET

A Nimonic 75 carburizing box being withdrawn from a furnace. The alloy gives exceptional resistance to oxidation and useful mechanical strength at very high temperatures. It is widely used in industry for countless other high-temperature problems.

*Trade Mark

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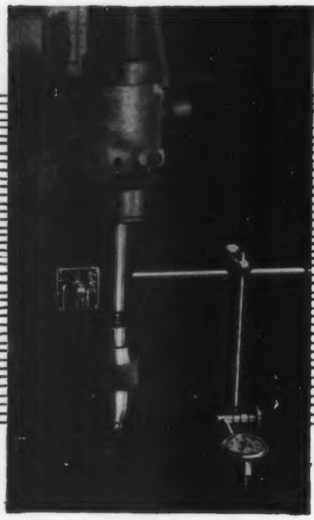
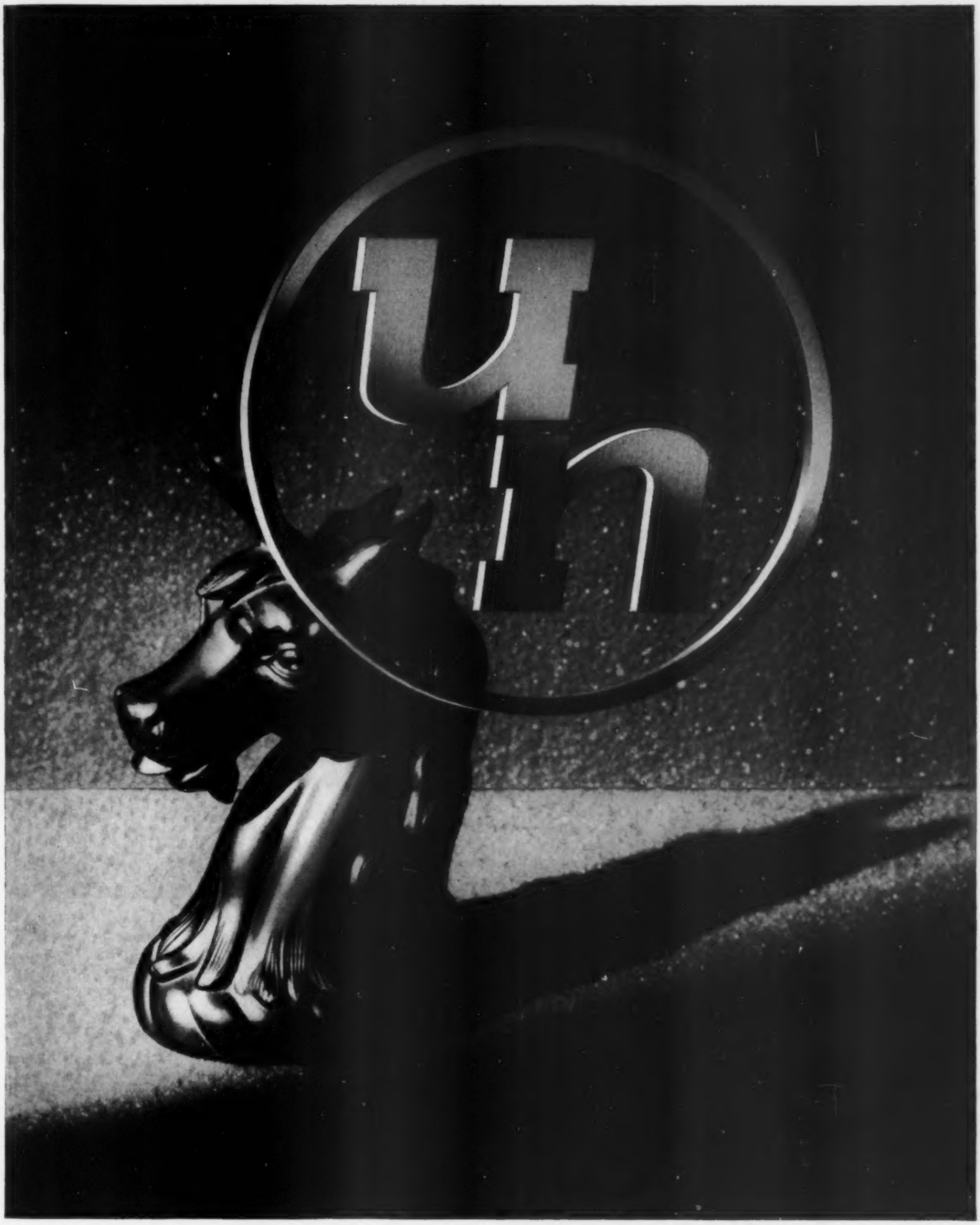
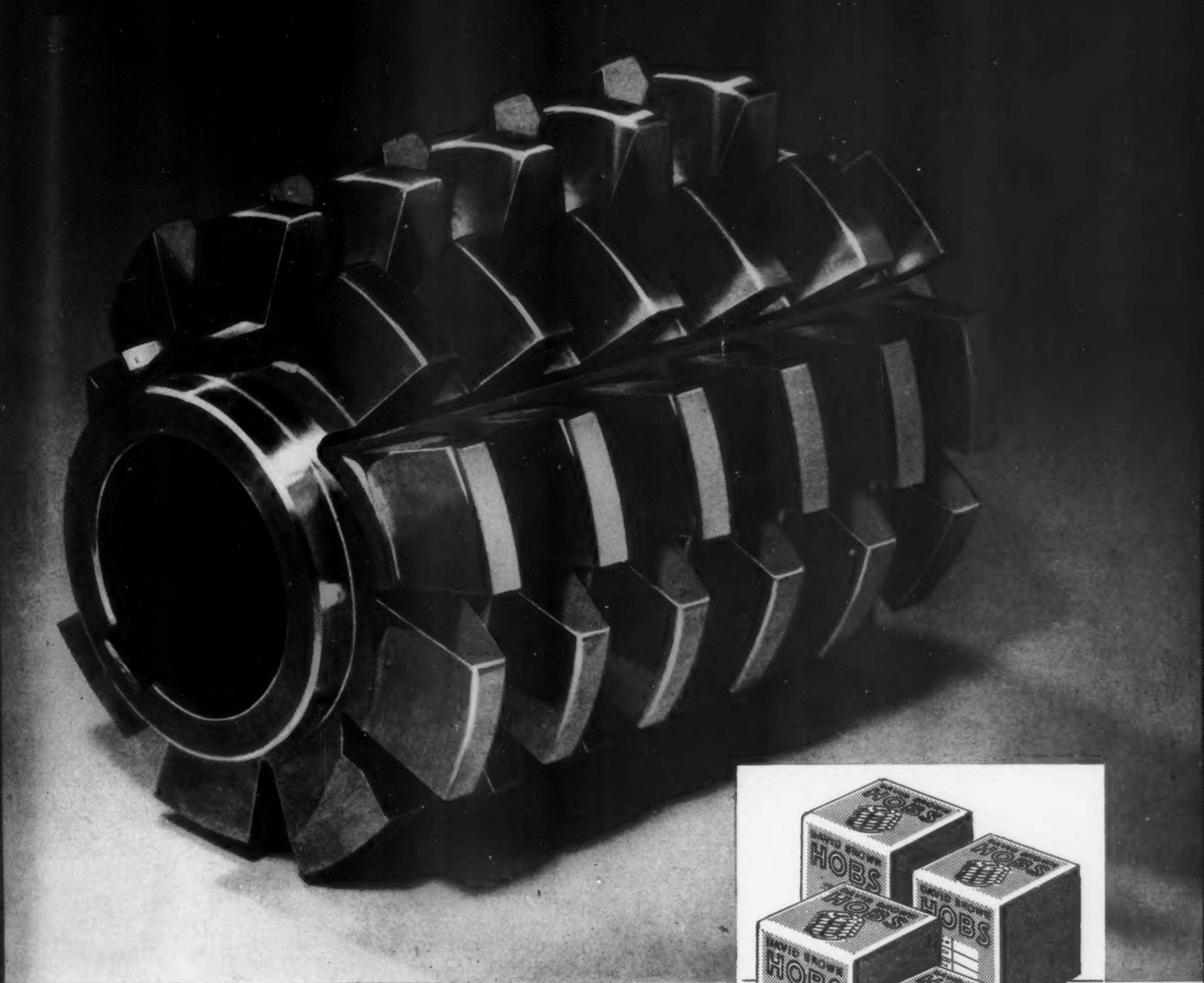
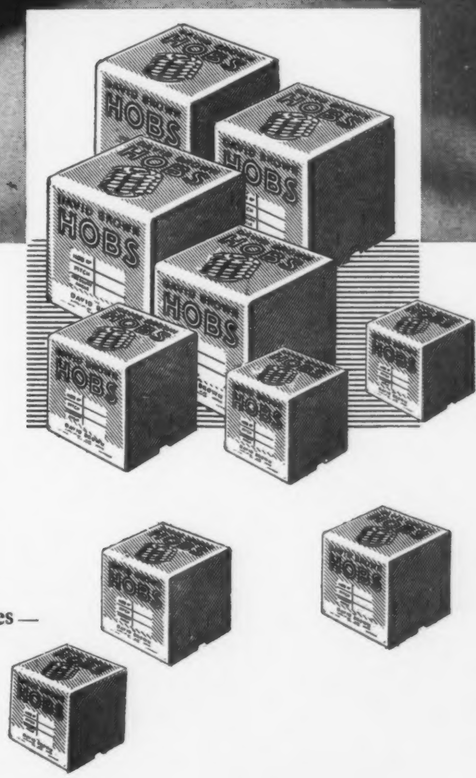






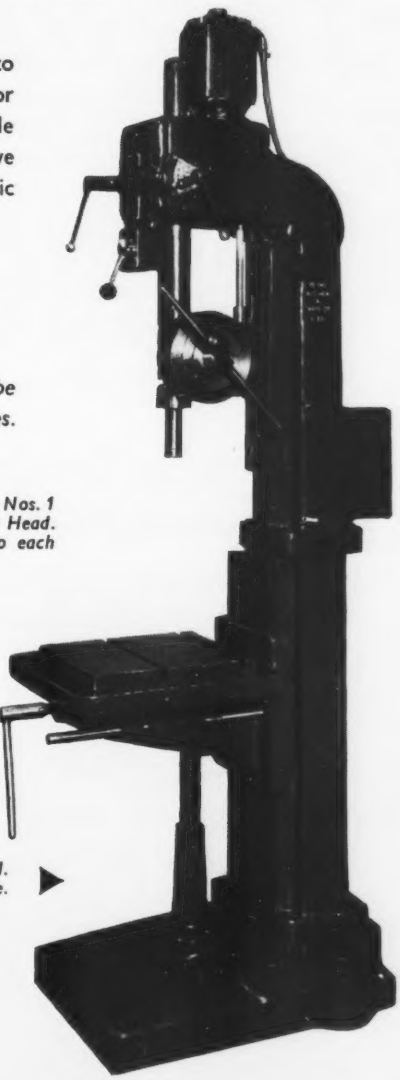

DAVID BROWN
HOBS

K&W

HIGH PRODUCTION
DRILLING MACHINES

Single or Multi-Head Machines 1, 2, 3, 4 or 6 Spindles

TYPE V20



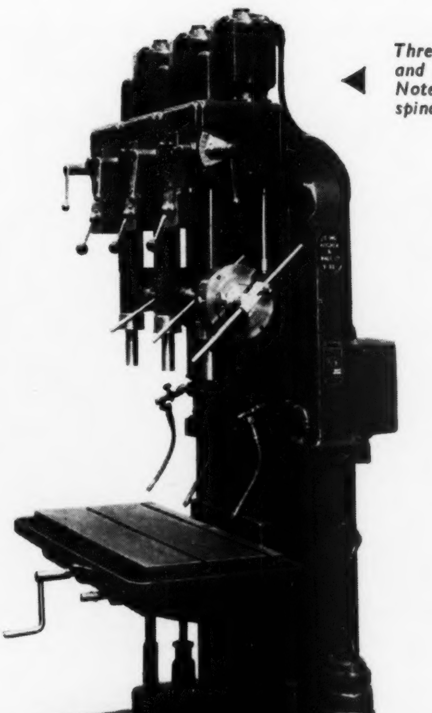
A simple, economic and efficient drilling machine for capacities up to 1 in. diameter in mild steel and when required with reverse to spindle, for tapping up to 5/8 in. diameter in mild steel. A 1 h.p. motor gives 9 spindle speeds through sliding gears. The V20 machine is available with sensitive hand feed only or with 4 rates of power feed and sensitive feed. Automatic trip for depth control is fitted to all machines with power feed.

Reverse to spindle for tapping is offered in two forms:-

1. Hand-operated electric reversing switch.
2. Automatic by pre-set adjustable trips controlled by spindle travel.

Both table and spindle head have vertical adjustment.

Write for full details of the V20 K & W machine which can also be fitted with various multi-spindle drill heads with fixed or adjustable centres.



Three Head Machine. Hand Feed on Nos. 1 and 2 Heads, power feed on No. 3 Head. Note Coolant Pump and fitting to each spindle.

A single head. Type V20 Drilling Machine.

DIMENSIONS	
SPINDLE CENTRE TO COLUMN FACE (STANDARD MODEL)	8½ in.
SPINDLE CENTRE TO COLUMN FACE (EXPORT MODEL)	12½ in.
LENGTH OF FEED (HAND OR POWER)	6 in.
NUMBER OF SPEEDS	9
TABLE WORKING AREA	15½ × 13 in.
H.P. OF DRIVING MOTOR	1 H.P.

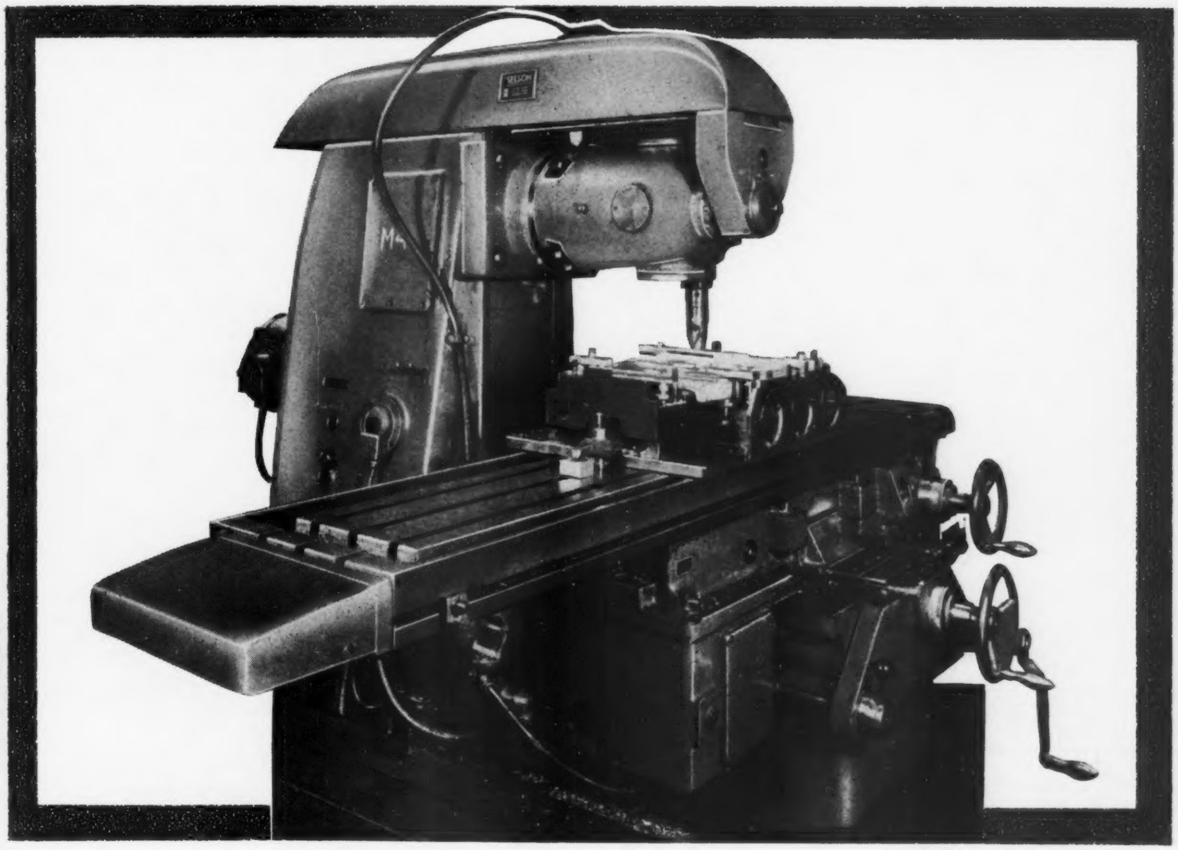
KITCHEN & WADE LTD. *Member of the Asquith Machine Tool Corporation*

ARUNDEL STREET, HALIFAX, ENGLAND *Telegrams : 'KAW, Halifax'. Telephone : Halifax 67744 (3 lines)*

KW375

ZBROJOVKA MILLERS

for precision milling operations



EARLY DELIVERY OF ALL MODELS

Complete rigidity at high speed is a feature of the Zbrojovka Millers. The Machine illustrated is the FA5H Horizontal Miller in operation at the Farlington works of Messrs. C. J. C. Developments (Portsmouth) Ltd., who have courteously permitted us to publish this photograph. Write or telephone for full details.

BRIEF SPECIFICATIONS OF HORIZONTAL, UNIVERSAL AND VERTICAL MILLERS

Sizes	No. 2	No. 3	No. 4	No. 5
Working surface of table (approx.)	40" x 8"	50" x 10"	64" x 12"	80" x 16"
Power Longitudinal travel (approx.)	25"	32"	40"	50"
Power cross travel (approx.)	8"	9"	12"	16"
Spindle speeds	62-2800	45-2000	32-1400	18-1400

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MACHINE TOOLS

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THE 600 GROUP OF COMPANIES

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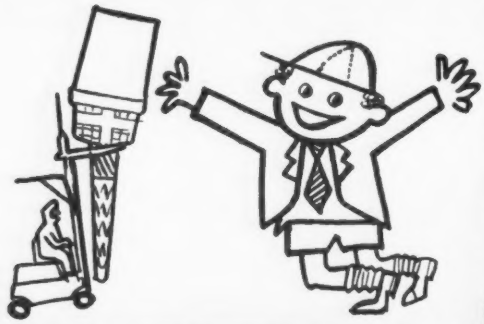

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.... and to meet these unusual Deep Freeze conditions Coventry Climax have developed special Electric Fork Trucks as illustrated alongside at work in the Wall's Ice Cream Factory at Acton.

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